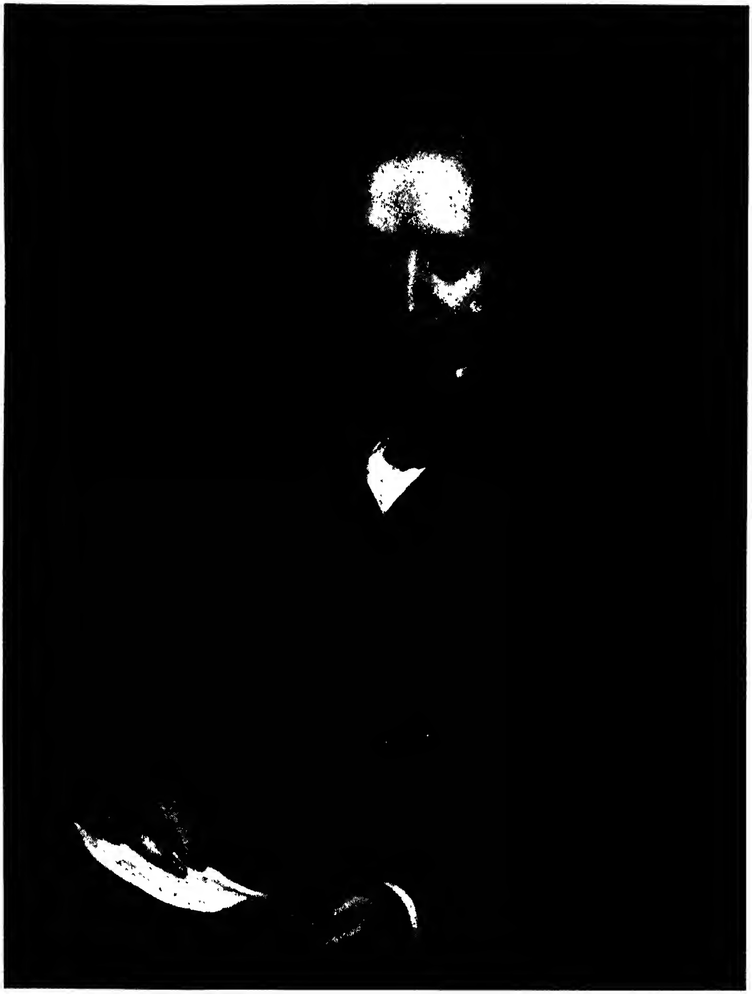
PLATE I

Frontispiece



Sir George Cayley, 1773-1857

The first man of science to apply his mind fully to the problem of mechanical flight and to attempt to explain mathematically its fundamental principles. (*See Page* 68)

MINISTRY OF EDUCATION

SCIENCE MUSEUM

INTERPRETIVE HISTORY OF FLIGHT

A SURVEY OF THE HISTORY AND DEVELOPMENT OF AERONAUTICS WITH PARTICULAR REFERENCE TO CONTEMPORARY INFLUENCES AND CONDITIONS

By M. J. B. DAVY
F.R.Ae.S.

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PREFACE

AT THE BEGINNING of the twentieth century an event occurred which, in its ultimate effects, is without parallel in history. That event was the achievement of mechanical flight. The idea that rapid transport could solve many of the problems with which mankind was confronted had gained strength with the industrial developments of the nineteenth century. It became, at once, all important, but full realization could not be until travel in the air was made possible; that had been the dream of centuries, had exhausted the skill of investigators, and had exacted a toll of life in fruitless effort. At last the greater difficulties were overcome, and means were found to journey in the medium which is all-pervading with regard to the earth's surface, unobstructed and thus free. What immense possibilities that accomplishment offered! It promised, ultimately, no natural restriction and was subject only to the will of man.

The history of aeronautics, which should include all human activities relating to flight, covers such a long period and is so complex that a complete account of it has yet to be written. It is not the purpose of this book to attempt such an exhaustive survey, but rather to try and explain the outstanding phases, facts and events in the light of contemporary human development and to provide a coherent narrative. The average man or woman of to-day, it is thought, desires the presentation of this subject in a form which embraces more than bare facts and technical details unrelated to the prevailing conditions and influences. That a part of the technical history of flight should be darkened by controversy is understandable when one realizes how rapidly it developed and the inevitable conflict of interests, but the broad outline should remain unobscured and its relationship to human affairs undisputed. Unfortunately, the closeness of that relationship has, up to the present, resulted in the flying machine being developed as much for the ultimate destruction of human intercourse as for promoting it, and the invention which presented difficulties so formidable as to constitute a signal achievement, has often proved in use retrogressive.

The employment of aircraft for destructive purposes is but one illustration of the fact that man's scientific knowledge of the material world has outstripped his knowledge of his own mind and society. The history of mechanical flight shows that this is the case, and, in the light of evidence here assembled, only one conclusion appears possible, *i.e.* that if the great power of flight is to be used to the best advantage it must be controlled by universal agreement. Also, in the present stage of human development, there is no other way by which the risk of its misuse can be avoided. This conclusion is discussed in the last chapter.

The book is divided into three parts—The Origins, History and the Modern Phase—and into fifteen chapters of which three are distinguished as dealing with great periods of achievement; the prinicpal event, from the standpoint of history, being the accomplishment of mechanical flight in an aeroplane by the Wright brothers on December 17, 1903. An endeavour

has been made to maintain a strict chronology, and the only notable departure therefrom will be found in connexion with the development of the airship, which is described in the chapter following the revelation of the lighter-than-air principle and the invention of the balloon. It is felt that this method is justified as it enables the evolution of lighter-than-air aircraft to be outlined in a continuous narrative and distinguishes it from the larger subject.

An acknowledgment is due to the National Aeronautical Collection at the Science Museum, which has provided the stimulus and constituted the basis for this book. Contact with the original apparatus used by the pioneers of flight brings a sense of reality to the early experiments which is not easily obtained from writings, and exhibits are the most valuable evidence. The formation of a collection illustrating the history of aeronautics was begun before the First World War, but not until 1919 was it found possible to organize it as a distinct and permanent exhibition representing the development of a new means of transport. Since then it has grown rapidly and is now the most comprehensive, if not the largest, of its kind in the world, including as it does a replica of the original Wright aeroplane and many other historic machines. It is to this source of information that the author is most deeply indebted.

As any interpretation of history must be largely a matter of opinion, it is desirable to emphasize here that the views expressed are those of the author personally and should not necessarily be regarded as representing an official attitude.

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PART I. THE ORIGINS

I. FLIGHT IN NATURE

THE PHENOMENON OF FLIGHT in nature was, of course, the inspiration for the idea of human flight; it constituted the basis and was the only model. It is doubtful whether man would ever have conceived flight if nature had not provided the pattern. That a medium so light and unsubstantial as the air, can support a heavy weight is, even to-day, hardly comprehensible to many, and it is probable that without the example of nature, man would never have thought of contriving machines which would fly. Thus it was that nature—and the bird's wing in particular—was the inspiration for human flight, and any attempt to interpret history must include a brief consideration of the natural phenomena from that standpoint. The whole subject of flight in nature with regard to what has and still may be learned is, manifestly, beyond the scope of this book.

All creatures which fly are heavier than air, so that there is no counterpart in nature of a flying machine which is lighter than air, *i.e.* the balloon or airship.* This fact has actually been advanced as an argument against the development of such machines, but the reasoning is obviously false in so much as several of man's greatest inventions have no natural counterpart—for example the wheel. It is true that the bones of some birds, notably the Gannet, are lightened by air-sacs which penetrate into them and contain air at a higher temperature and therefore lighter than that of the surrounding atmosphere. This may have the effect of slightly reducing their weight without reducing their strength, but they are still considerably heavier than the air they displace. Thus in studying flight in nature we are concerned only with organisms which are heavier than air, and all these function by virtue of surfaces moving through the air.

In nature the power of true flight is confined to a few mammals, to some reptiles (now extinct), to most birds and to some insects. A number of animals are able to move through the air by scudding, gliding or parachuting—moving as the result of gravity with only an initial expenditure of energy—but they are not true flyers. The flight movement of the so-called Flying Fishes has been a subject of much contention, some observers maintaining that they have, in a limited degree, the power of true flight; others that they exert no propulsive effort while air-borne. The latest evidence shows that such is indeed the case and that propulsion is effected solely by the tail acting against the water. The largest flying creature of which we have any knowledge is the extinct Great Pterodactyl (Ornithostoma) of the Secondary or Mesozoic Period. The skeleton of this reptile, restored from the Cretaceous of Kansas, indicates that its wings, when outstretched, had a spread of about 20 ft. from tip to tip and its weight, as estimated, was only 25 to 30lb.† The body was

*Lycosid spiders are sometimes described as having a "ballooning" habit, but, though they drift with the wind, they are heavier than air. In still air they would descend vertically.

† Smithsonian Report for 1901.

very small and the head, with its large beak, nearly 4 ft. long. As in the case of other animals (birds) with long and narrow tapered wings, it is assumed that the Great Pterodactyl was essentially a soaring creature and that, as it attained such dimensions, its flying performance was good. It is, however, certain that the flight efficiency was less than that which has since been reached by man, though it appears to have been more highly specialized than any other flying animal.

The Pterodactyl had peculiar characteristics, and this brings us to a consideration of the remarkable fact that the power of flight has been evolved independently in different groups of animals, *i.e.* pterodactyls, bats, birds and insects—modifications and changes in the structure of the body having taken place for the purpose of locomotion in the air. Moreover, the wings or supporting surfaces which enable the animals to fly have not been inherited from the ancestral stock from which they all originated, but have been evolved independently in accordance with the creature's need; thus migratory birds are equipped for that purpose, which is an economic necessity to their survival. The animals which fly are all either vertebrates (backboned animals) or insects; and in three groups of the former, research has shown that a pectoral limb has been transformed into a wing, but the transformation has been differently effected in each case from fundamentally similar types of wing skeletons.

The supporting surfaces in the case of the extinct pterodactyls and in bats, consist of skin stretched between the arm bones and the body, but the extension of the skin in its particular terminations is different in the two species. In the case of birds, the surface which affords resistance to the air and gives support is wholly different, being composed of feathers which overlap one another in such a way as to present an almost continuous layer, and they are attached (at their basal ends only) to the bones of the forearm and hand. The development in nature of two different forms of wing covering—the skin and the feathers—will, by itself, serve to show the independent character of the evolution of the power of flight and it is not necessary to go further to demonstrate this general fact. It is, however, particularly interesting to consider that the fore-limb, which is the basis of the wing in a pterodactyl, a bat and a bird is, in essential construction, similar to that in man; the proportions, of course, differ considerably, but the fundamental structure is the same. It is not suggested that this fact has any bearing, other than the obvious one, on man's early attempts to imitate nature by attaching wings to himself, but it does show that in natural development he is nearer to the equipment necessary for flight than are many of the non-flying animals.

The animals which impressed mankind most were doubtless those whose flight performance was best, but the distribution of those species was limited geographically and numerically and one can only vaguely estimate inspiration at any given time and place. Birds, whose distribution was widest and whose variety was greatest, must have constituted the primary inspiration. From mythology, legend and, later, recorded fact, we can select, almost at random, a dozen species which are shown as providing the inspiration and basis for some early endeavour. Thus, Kung-shu Tse, a contemporary of Confucius, is said to have carved a magpie (a notoriously bad flyer) from bamboo and wood, which " artificial bird " (in all probability some form of kite) remained aloft for three days. The Greek, Archytas (*c.* 428-347 B.C.) is said to have

adopted the dove as his model, and his flying bird was one of the wonders of antiquity. It is not clear from the different descriptions of this wooden bird how it functioned—if indeed it ever did so—or on what principle it was based. There seems to be complete agreement only in the statement that it took the form of a dove. The use of animal power in the form of trained eagles, kites and other birds to support and draw aerial chariots and the like, was contemplated from the earliest times. We find in the ancient semi-legendary history of Persia that a king was raised and supported on a throne by four eagles which were induced to perform in that manner by four pieces of flesh fastened to the tops of four spears attached to the sides of the throne (see Plate II). The selection of eagles in this case was obviously appropriate for the work to be done ; and it is interesting to note that right through history the same project recurs.

In modern times the best inspiration was drawn from the finer exponents of gliding and soaring flight. We find that the great students of bird flight, Louis Pierre Mouillard (1834–1897), Otto Lilienthal (1848–1896) and others, observed and drew inspiration from such species as the Albatross, the Buzzard, the Stork, the Sea Gull and the Kite. It was, of course, the excellence of the flight performance which impressed them, particularly the ability to soar and to glide for long periods with wings apparently motionless. The significance of soaring flight was at last apparent; previously speculation had been based mainly on flapping wings.

The Albatross is probably the finest exponent of soaring and gliding flight among birds capable of sustained periods in the air. It is not uncommon for it to remain on the wing continuously for several days, and practically the whole flight consists of soaring and gliding, flapping the wings being employed only for the initial take-off or occasional additional impulse. The remarkable streamline form and thick tapered wings evolved by nature in the Albatross for this purpose are its most important characteristics, and they have been reproduced in the design of aircraft with considerable success. The chief method of flight employed by this bird has been described as "dynamic soaring," which requires continuous wind of relatively high velocity, hence it is only to be found in southern seas where such winds invariably prevail. Deflection currents which occur at lower altitudes are used by the Albatross only to enable it to reach its nesting site. The method of flight, as it has been observed, is interesting; it consists first in attaining an air speed of about 50 miles per hour, when the bird turns into the wind and soars. The loss of forward motion resulting from this climb is compensated for by the increase of wind velocity owing to increase in altitude. At a height of about 50 feet the bird banks sharply, makes a rapid turn, and proceeds to glide steeply with the wind, thereby increasing the speed in readiness for another turn into the wind for a further climb.

Unlike the dynamic method of soaring employed by the Albatross, the Gannet, which is to be found in several large colonies off the coasts of the British Isles, relies principally on what may be described as "static soaring." In this case use is made of rising air currents caused by the wind deflection resulting from cliffs, hills, houses, etc., lying in the path of a wind and causing the airflow to be directed upwards to pass over the obstacle. Birds in such conditions receive a lifting component of the movement and rely on it. The Sea Gull may frequently be seen using the same method for soaring. There

are two localities in the British Isles which are particularly suited to this method of soaring flight; they are the Bass Rock in the Firth of Forth and Ailsa Craig in the Firth of Clyde. In each locality enormous numbers of Gannets, congregating during spring and autumn, have their nesting sites and bear evidence of the wonderful evolution of flight in a species in accordance with its particular needs and the natural phenomena of the air currents.

The Albatross and the Gannet are particularly interesting as examples of flight in nature because they illustrate two fundamentally different methods of flight which have their counterpart in modern aircraft. The former is essentially a soaring bird, and not a power-flyer in the sense that it seldom exerts a propulsive effort, and is actually unable to rise, except from rough seas, owing to the peculiar shape of its wings; it has thus a direct analogy in the modern high-performance sailplane or glider—the motorless aircraft which has the important characteristics already referred to. The latter is a bird endowed with remarkable powers of flight, but, unlike the Albatross, it is a power-flyer in addition to being proficient in gliding and soaring and also in diving at great speed. Its wings are so shaped as to allow of their being used for the propulsive effort of flapping, normal to most birds, but, in consequence, there is some lack of the special qualities necessary for very prolonged soaring flight. It has a fine streamline form and there is thus an analogy in the modern power-driven aeroplane.

Observation of the flight of birds in a scientific manner has extended over a period of more than four centuries. As will be seen later, Leonardo da Vinci was probably the first actually to record some rational principles as the result of his observation, but his statement of principles was not made known to the world until 1797. His projects (apart from two original inventions of fundamental importance) were based on the imitation of nature in flight by the flapping of wings, so that the inspiration he drew from nature, in common with many savants who followed, was not primarily the inspiration of soaring flight, and the full significance of it was not apparently realized. The negative character of proposals to imitate nature by the flapping of wings was demonstrated by Giovanni Alfonso Borelli in 1680 in his critical work "De Motu Animalium," to which reference will be made later. Nevertheless the idea persisted for centuries, but to-day it has no place in serious thought, the influence of nature being seen in form rather than in mechanism. For nature excels in forms evolved to reduce resistance to enveloping fluids—*e.g.* in fishes—and much is still to be learned in that subject. It is significant, in view of the current tendency in the design of aircraft, that no superposed, multi-plane forms are to be found in nature, but only monoplanes, and that the remarkable phenomenon of insect flight has yet fully to be explored.

The flight of insects is remarkable for diversity of performance, ability varying very considerably with different types—as exemplified by the slowness of the moth and the rapidity of the dragonfly. A characteristic of some insects is the power of extremely rapid manœuvre—an accomplishment which deserves further investigation—and the ability to land in a very small area comparable with their size. The amount of run required to "take off" is also remarkable, being less than in the case of birds, and it would appear that nature has evolved organisms of the greatest efficiency in the small scale of insect life.

In the history of aeronautics, the stage at which the function of the bird's wing when held rigid, or nearly rigid, in gliding and soaring flight was beginning to be understood and its significance realized, is of great interest and importance. It is impossible to say exactly when the inspiration first came, but it was certainly present at the beginning of the nineteenth century when Sir George Cayley (1773—1857), who based his theories on his observation of nature, defined the main principles of human flight. His consideration of the theoretical basis of a curved wing in operation—a subject which will be dealt with later in this book—shows that his observation of natural flight was more acute and enlightened than that of previous investigators. He was inspired to apply the principle of the outspread wing of the soaring bird to the construction of a glider which he described as a " great white bird," and with which he made experiments.

The phenomenon of gliding flight impressed other investigators, who appear to have realized that human flight might be accomplished if the underlying principles of gliding could be understood and applied. Thus Jean Marie Le Bris (1808–1872) having observed the remarkable powers of the Albatross sought to imitate it, and Mouillard, whose observations and conclusions were published in 1881 in a remarkable book ," L'Empire de l'Air," was similarly inspired.

The first practical and successful application in full scale of the principle of gliding with wings stationary and rigid was made by the great pioneer of artificial gliding, Otto Lilienthal, who may be said to have created the art which led to mechanical flight. The history of the development of gliding flight comes later in this book; it was the art which marked the first stage in the practical, as opposed to the theoretical, evolution of the aeroplane, because it involved actual practice in the air, and it represented the sum of the inspiration then drawn from nature.

II. THE EVIDENCE OF MAN'S PRIMEVAL DESIRE

EVIDENCE OF MAN'S DESIRE to emulate nature in that accomplishment naturally denied to him is contained in the works of art of the earliest civilizations, and in the traditions and legends of many peoples. To describe only the gradual perfection of the mechanical devices which made flight possible does not constitute a complete history of aeronautics. The idea which inspired the development of those devices is paramount—the will to fly was the will to conquer, to overcome all obstacles in the effort to gain control over natural conditions of environment, and it pervaded the mind of man throughout the earliest civilizations.

The idea of human flight was derived inevitably from the contemplation of nature and it appears to have been one of the loftiest aspirations of mankind from a remote period. The restriction of man in contrast to the freedom of the birds was regarded in the earliest times as indicating an imperfection in bodily structure, and from this conviction there arose conceptions of higher beings endowed with the power of flight. In mythology and folk-lore such beings were represented as equipped for winged flight or, in default of this, were capable of being transported by other means. As reason developed, flight was regarded not as a supernatural achievement—since flight was common in nature—but as an accomplishment which, though denied to man, involved no transcending of natural law. The realization that flight was a physical phenomenon and not a manifestation of the supernatural was the beginning of a long period of speculation as to the best means whereby it could be achieved, and innumerable attempts were made to imitate the birds by the use of artificial wings and similar devices.

The earliest attempts to fly, that is to travel freely in the air, cannot, as will be shown later, have been other than abortive—no measure of success was achieved—but they were, in all probability, the foundation for the classical legends which caused the idea to endure during periods when the spirit of conquest was waning. It has been said that the imaginative faculty of the human mind is unable to conceive things that have absolutely no reality in existence, and that, because primitive man was unable to render an intelligent account of the practices of his day, the records are necessarily incomplete and any sweeping assumption of failure unjustified. But the scientific principles underlying flight are now well understood and, in the light of that knowledge, it is clear that most of the alleged flights, as they are described in mythology and legend, are physically impossible. The author holds that it was only the fact of an attempt which provided the foundation for legend.

It appears that the earliest legend of an attempt to fly is that relating to the Chinese Emperor Shun, of the third millennium B.C. (traditional date, 2258–2208), who, it is recorded in the commentary to the authentic "Annals of the Bamboo Books," made his escape from captivity when a boy by donning the "work-clothes of a bird."* More explicit is the account of his safe descent

* Laufer, B. Field Museum of Natural History, Pub. 253, Anthropological Series, Vol. XVIII, No. 1.

from the top of a tower by means of two large reed hats which, when spread out, presumably acted as parachutes to reduce the speed of his fall. The story is certainly more credible, and in view of the fact that such reed hats may be as much as 3 ft. in diameter, it probably had a foundation in some actual attempt.

The tradition of human flight was as widespread in the Orient as in Europe, and according to the late Dr. Berthold Laufer who made a special study of the subject, it antedated by many centuries that of the Western world, which is better known to us by reason of legends which have become classic. The conception of "bird-men" is found in ancient Chinese mythology, as indeed it is throughout the East and, according to a recent discovery, in the South American continent also. These "bird-men" as depicted in monuments and sculpture are frequently deities, and they are attended by other winged figures who have often the attitude of adoration, holding gifts or offerings.

It is significant that the first record of human flight in the history of the East is that of a royal personage (the Emperor Shun), and in the West the legendary tenth King of Britain, Bladud (who died 852 B.C.), is credited with making a similar attempt—the first recorded in England—and, it is said, he lost his life thereby. The story is recorded by Geoffrey of Monmouth (A.D. 1100–1154) in the "Historia Regum Britanniæ," written about 1147, and first printed in 1508. Bladud is described as a necromancer skilled in the art of magic, and his attempt to fly, and endeavour to maintain his reputation as a performer of magical tricks. In China and elsewhere, attempts at flying were connected with magic, presumably because they were not understood, and tradition handed on both Shun and Bladud as magicians. The latter's attempt to fly by "Necromanticke Arts" (which we may interpret as the "scientific" knowledge of the time) may have been the result of his alleged study at Athens, the universal centre of learning of the period, or the story may be merely an invention of the twelfth century, but its significance as an indication of the enduring trend of thought remains.

It is convenient to assume that, in what may be termed the pre-history of human flight, the order was that of aspiration, speculation and discussion—leading to some abortive attempts which became the subject of imaginative romance in the mythological and fabulous stories which have been handed down to us. In China, In India and in other parts of Asia, the tradition of human flight was widespread, and in the case of China it appears to have antedated that in Europe. It must be admitted, however, that the many Chinese fables which have been cited as evidence of aspiration, if not indeed of actual endeavour, are most unsatisfying and unconvincing to the ordinary student. A coherent interpretation of them seems impossible; their essence appears to be pure romance, which is perhaps understandable when one reflects that it is the marvellous and romantic which lingers in the memory of man. It is significant that some of the fables have a close parallel in mythology and legend of the West, but little meaning which is tangible accrues. In the early history of China one comes with relief to the first record of the existence of the kite—the earliest practical flying device—which, from all the evidence available, had its origin there.

The most classic legend of aeronautics, that of Dædalus and Icarus from Greek mythology, is either entirely fabulous or refers to something quite

different to actual flight; but of all the flying fables of antiquity it seems to have created the most lasting impression on subsequent generations, and it probably stimulated many to imitate. The importance of the story is in its moral effect: Dædalus (" cunning artificer ") was a personification of mechanical skill and it was reasonable to suppose that he made some attempts to fly—therein lies the significance of the myth (see Plate III).

Tiberius Cavallo, who in 1785 published his remarkable work on the history of aerostation,* made some astute comments on the historic legends of flight. His comments were so shrewd, being apparently the result of a careful examination and consideration of all the classic literature, that they deserve special mention here. He observed that the tradition of human flight might be the result of pure imagination; or it might be an art which was lost. Prior to the invention of the balloon (or the aeroplane) there appeared to be justification for the former opinion, but since the discovery of a means whereby man could raise himself into the air the aspect was changed—flight was proved to be possible physically—and the latter view appeared credible. Cavallo remarked that an art entirely forgotten has the same effect as an art never discovered, and that speculation concerning it is thus only of antiquarian interest.

The science of human flight was born in comparatively recent times; it derived nothing from antiquity save the desire to fly. But that desire was the product of romantic dreams and of imagination, and there is probably no field of man's endeavour in which they have played a greater part or proved more fertile than in the development of flight. The trend of the human mind towards romance and adventure was the origin of the modern achievement, and in the final analysis we must recognize that fact.†

* Tiberius Cavallo, F.R.S. " The History and Practice of Aerostation," London, 1875.

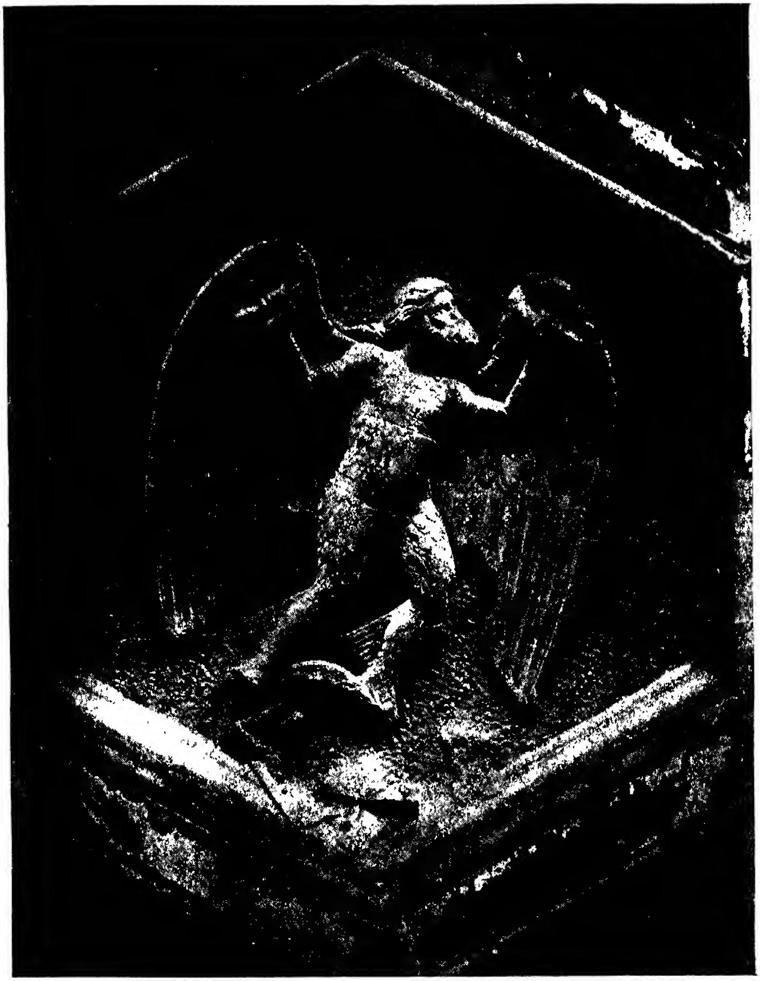
† The history of human flight does not appear to have been discussed from the standpoint of anthropology save in the publication of Berthold Laufer already referred to.

PLATE II

The Persian Legend of Kai Kawus

The use of eagles and other birds to raise and support a throne or chariot in the air was contemplated from the earliest times (*See Page* 3)

PLATE III



Dædalus

The Icarian legend created the most lasting impression on subsequent generations (*See Page* 8)

III. PRIMITIVE AERONAUTICAL DEVICES

THE PREVIOUS NOTES HAVE dealt with the evidence of man's desire to fly and the phenomenon of flight in nature which inspired him. We cannot regard the early legends of flight as providing conclusive proof of experiments having been made, though it is very probable that they were and that attempts to fly formed the basis of some of the legends. For precise evidence of construction and experiment we must await the introduction of the kite—the earliest known example of a practical heavier-than-air flying device, and an invention the full significance of which does not appear to have been realized for some two thousand years.

The evidence relating to the origin of the kite and to the early history is obscure, but it is generally accepted that the Chinese were the inventors. The exact date of its introduction is uncertain, but records—not contemporary—show that kites were used in China for military signalling in 206 B.C. It is unwise to assign the invention to an earlier date, or to attribute it to Archytas (fourth century B.C.), as has sometimes been done, for the evidence is inadequate. From China the practice of flying kites spread to India and from that country gradually extended westward until it reached Europe. The earliest known representation of a kite in England is contained in "Mysteries and Nature of Art," by John Bate, 1635.

The functioning of a kite is quite simple: it is an aerodyne (the generic term for aircraft which derive their lift in flight chiefly from aerodynamic forces) which is anchored or towed by a line and is not mechanically driven. It consists of a plane or planes which, as a result of aerodynamic forces, or to express it more simply the upward thrust of the wind, mounts in the air while it is restrained at the proper angle by a string held by the operator. The principle demonstrated is that a plane surface can be supported in the air if there is a wind blowing and if the surface is held at a suitable angle to catch the wind. Moreover—and this of even greater significance—if there is no wind at all and the operator runs very quickly pulling the string, the kite will rise and move through the air. Actually what happens in both cases is that the pressure of air under the plane is greater than the pressure above it and so the kite rises. Here we have, inversely, the principle of the power-driven aeroplane as it was demonstrated over two thousand years ago.

In China kite flying has always been a popular pastime and great ingenuity has been displayed in devising creations which are wonders of both technique and of art. The ordinary Chinese kite (which has probably changed but little since its inception) is made of a light and elastic diamond-shaped framework of bamboo over which a sheet of strong paper is spread. It is painted in brilliant colours with figures, human or animal, and displays all that love of art and decorative design which is characteristic of the Chinese people. A great variety of quaint shapes and designs are found in addition to the ordinary or " paper kite " which is most in evidence. In the cases of kites representing birds, thin paper is attached which being moved by the wind simulates the flapping of wings. A tail, which affords stability, is fitted

in the ordinary kite, but other flat types are tailless, the frame being flexible so that the surface adapts itself to irregularities of air flow, and they are flown at a relatively large angle to the wind.

Other types, known as "dragon kites" and "centipede kites," consist of a number of light elliptical or circular discs formed of bamboo covered with paper and strung out in line, equally spaced, on two cords. In some cases the discs gradually decrease in size from head to tail of the figure represented; in one particular example twenty-five discs, each 1 ft. in diameter, were used and the whole measured 40 ft. in length when in flight. In such cases the discs are inclined at an angle of about 45° to the wind. Dr. Laufer mentions having collected some seventy kites, all of different types, which gives an indication of the diversity in design, but in every case, of course, the underlying principle is exactly the same. The remarkable fact is not the variety of forms evolved over a long period, but that the invention, so early made, was not sooner developed and applied for human locomotion—its profound significance was apparently unrealized. We find that not until the nineteenth century was the kite experimented with scientifically for man-lifting purposes (though two hundred years before, it is said, kites had reached such dimensions), and that only at the beginning of the twentieth century did the Wright brothers (who first achieved mechanical flight) apply the principle of operation when they tested their gliders in the manner of a kite.

It would be interesting to know exactly how the kite was first conceived; whether it was a discovery accidentally made or whether it was born of an inspiration from nature. Mechanically it represents the principles underlying the soaring flight of a bird and therefore it is reasonable to regard it as the result of an inspiration from nature. If we do, it constitutes the first real fruit of such inspiration, but not of immediate profit like that of the nineteenth-century glider which was based on observation of the same natural phenomenon.

The form of Chinese kite which most resembles the first successful glider—that of Otto Lilienthal—is the type known as "musical kite," by reason of the fact that it is generally provided with a resonator device, in the form of a piece of bamboo, containing three apertures, which produces a plaintive sound while in the air. The significant feature of this type of kite is that it approaches most nearly to the shape and attitude of the wings of a soaring bird. The kite is formed on a stiff bamboo rod with two lighter transverse rods which curve upwards, being connected at their extremities, thus giving the appearance of two bird's wings fixed to a central axis. The surface is curved and to some extent flexible, and the attitude in flight resembles that of a soaring bird. It is stated that kites of this type have reached large dimensions—up to about 10 ft. in span—but there is little evidence to show when the type originated. From the standpoint of natural flight it may be regarded as the highest development, historically, of the kite.

Another device, probably of great antiquity, may have originated in the Orient. It is the "Chinese," or flying, top—a device which serves to illustrate the principle of the airscrew and a particular application of it, *i.e.* for lifting purposes. In the absence of any authentic evidence regarding the inception of the "Chinese" top, or even the date of its introduction into Europe, the credit for having first conceived the lifting airscrew, or helicopter, belongs to Leonardo da Vinci, who described it about the year 1500.

Sir George Cayley employed the "Chinese" top in an improved form* and also experimented with "a simple machine for rising in the air by mechanical means" in 1796.† The former consisted of three thin metal vanes set at an angle of about 25° to the plane of rotation and mounted on a vertical spindle which rested freely in a wooden holder. The upper part of the front or leading edge of each vane was cut away in order to obtain a fine entering edge. The method of operation was to rotate the spindle rapidly in the holder, by means of a cord wound round it, when the airscrew would rise to a considerable height, thus demonstrating the principle of the helicopter. This airscrew was capable of rising to as much as 90 ft. in the air. It would be interesting to know how much Cayley's improved design of flying top differed from the prototype, and in exactly what form and where he first observed it. Stephen Coulson, an engineer of Redcar, also experimented with a similar device and we find that, in 1843, Cayley was corresponding with him on the subject of screw propulsion, both in air and water, and also, in 1854, with Depuis Delcourt in France.

Previously, in 1784, MM. Launoy and Bienvenu had exhibited before the French Academy of Sciences an apparatus consisting of two superposed airscrews, about 1 ft. in diameter, each in the form of four feathers and so arranged at the top and bottom of a rod that they could be made to rotate in opposite directions by means of a cord unwound by the tension of a bow drawn taut in winding. Was this the form in which the airscrew was invented? It was understandable that, when investigators found the flapping wing or ornithopter principle was not feasible for mechanical flight, they should turn to the screw as a means for support in the air. The idea of the lifting airscrew had been revived by the French mathematician Paucton, who published a treatise, "Théorie de la vis d'Archimède," in 1768—a treatise which described a projected apparatus, the *Ptérophore*, consisting of two airscrews, one for sustentation and the other for propulsion. This proposal bore the stamp of revival of an ancient idea—the idea which prompted Leonardo da Vinci to suggest an instrument consisting of a helix turned at great speed. But Leonardo did not invent the helix, and it is possible that the "Chinese" top long antedated his application of the same principle.

A third device, the parachute, an apparatus acting on the resistance of the air to break the fall of a body, was formulated also by Leonardo da Vinci in the fifteenth century, being described and illustrated in his manuscript known as the "Codex Atlanticus." There is no evidence that he actually constructed this device, but we may assume that the proposal was based on some experiments, either his own or those of earlier investigators. If we accept the legend relating to the exploits of the Emperor Shun (already referred to) as having a foundation in some actual attempt, the idea of the parachute, or "fall-breaker," is very ancient, and it ranks with the kite and the airscrew in antiquity, though of less significance. It found development in other hands for, about 1595, a Venetian, Fausto Veranzio, published‡ a modified design doubtless inspired by the sketch of Leonardo, but again there is no evidence that a descent was actually made, and it was not until the latter part of the eighteenth century that the idea was revived.

* Description of an "Improved Chinese Flying Top," H.M. Patent Office Library.
† Nicholson's *Journal of Natural Philosophy, etc.*, Vol. XXIV (November 1809), p. 172.
‡ "Machinæ Novæ," *c.* 1595.

Finally, there is the evidence of the feathered arrow—the significance of which appears generally to have been overlooked. The practice of archery is so ancient that the device of the feathered shaft probably antedates all aeronautical contrivances, yet it embodies the essential principle of plane surfaces used to act against the resistance of the air in order to ensure a straight passage though it. In order to keep an arrow true in " flight," feathers were usually tied to, or inserted in, the butt-end, and sometimes pieces of leaf or skin were used. These constituted surfaces in the same plane or slightly inclined to the axis of the arrow, and three were generally employed set at angles of 120° to one another. Obviously any deviation from the true flight path results in some of the feathers being presented to the air at an angle, and a righting force is thus automatically exerted. Alternatively the feathers were so arranged that they acted as an airscrew and imparted a slow rotary motion to the arrow in its passage through the air. The origin of the practice is lost in antiquity, and there are no means of ascertaining when or how it was discovered.

Returning to the kite, we find that the device was used in this country for meteorological research as early as the middle of the eighteenth century and that attempts were made to draw light carriages with it in 1826, and to employ it for life-saving from shipwrecks. But the essential lesson to be learnt from it seems to have escaped all experimenters until the last decade of the nineteenth century, when Lawrence Hargrave developed the box-kite and obtained important data concerning the best shape and arrangement for sustaining surfaces with a view to greater stability, more lift and less drag.* These were fundamental problems which the kite could help to solve.

* These experiments will be described later.

PART II. HISTORY

IV. SPECULATION AND THE IMITATION OF NATURE

From Early Times to the End of the Seventeenth Century

SOME STORIES OF HUMAN flight which emanated during the Middle Ages bear evidence of a changing attitude; the element of superstition is absent and it is replaced by what is clearly a human motive—the ambition to perform a feat wonderful and unique. The idea of flight, expressed in mythology as a supernatural attribute, became rational with the realization that it was a physical phenomenon. The rational attitude resulted in speculation and, inevitably, in attempts to imitate nature. Ambition to perform the wonderful stimulated many to attempt flight during this period of comparative enlightenment, and it is of interest to mention one or two of the more circumstantial tales.

The story of the Saracen of Constantinople is illuminating. Anxious to show his skill before the Emperor Manuel Comnenus (eleventh century), the Sultan of the Turks and a large concourse of people, he attempted to fly across the hippodrome at Constantinople. The Saracen climbed to the top of a tower of the hippodrome, where horse races were taking place, and announced that he would fly across the course. He stood in a long and very wide garment of white material which, it is said, was braced with rods of willow-wood on a framework. Leaning into the wind he finally left the tower, but, as an account says, " the weight of his body having more power to drag him down than the wings had to sustain him, he broke his bones and his evil plight was such that he did not long survive."

A similar adventure is ascribed to the English monk Oliver (Elmer or Eilmer) of Malmesbury, astrologer and mechanic, who, it is said, fitted wings to his hands and feet, and attempting (*c.* 1020–1040) to fly from a tower by the help of the wind fell and broke his legs. The story, as related by Milton in his " History of Britain," 1670, says that he flew more than a furlong, but the wind being too high he came fluttering down. The account states that Oliver was so conceited of his " art " that he attributed his fall to the lack of a tail which he had forgotten to make and fit to his " hinder parts." It is interesting to note that this story bears a striking resemblance to earlier Arabic accounts of flying feats, and some connexion between the two must inevitably be assumed. Possibly Oliver's attempt was made in imitation of an Arabic legend of which he had knowledge, or if there is no truth in the account of his attempt, the story may have been modelled on those legends. It is significant that this and other mediævel stories were regarded generally, by those who chronicled them, as acts of folly rather than of sin—an instance that the attitude was changing from the superstitious to the rational.

The age of more serious speculation in regard to the possibility of human flight found expression in the writings of the Franciscan monk Roger Bacon (1214–1292); certainly he was the first Englishman, of whom we have record, to refer to the subject in any rational sense. He represents a land mark

in human development, and though actually he contributed nothing to the subject of flight, his reference to it being merely a passing comment, the spirit which prompted that and his many other observations was remarkable in so far as it marked a stage in the escape of the human mind from its original limitation. His attitude in the pursuit of knowledge, which may be described as insistence on the importance of verification by experiment of all deductions by logic, was of profound significance, particularly when concerned with this age-long problem of flight. In effect, his standpoint was that ideas should be tested by experiment and that none, unless so proved, should be accepted. The method was that now known as "scientific"; it made use of logic, but it viewed the findings with distrust until verified by experiment.

In the light of this revolutionary but profound attitude, Bacon's writing on the subject of flight is disappointing; one might have expected much more. The reference he makes to it is only incidental, and he regards it merely as an interesting possibility. The passage occurs in "The Secrets of Art and Nature," written about the year 1250, and it has been variously translated and often quoted.* In the first English translation (1597) of that part dealing with inventions it reads as follows: ". . . yea instruments to flie withall, so that one sitting in the middle of the Instrument, and turning about an Engine, by which the wings being artificially composed may beate the ayre after the manner of a flying bird." And later: "And it is certaine that there is an instrument to flie with, which I never saw, nor know any man that hath seen it, but I full well know by name the learned man that invented the same."

It is significant that Bacon made no attempt to consider whether flight was practicable in the light of the knowledge of his day, moreover he disclaimed any precise knowledge of the "instrument" by excluding it from those mechanical devices which had to his knowledge actually been constructed. The qualification is characteristic in its caution, but it does not reduce the importance of the central fact that Bacon considered the project of mechanical flight worthy of mention—he was the first "man of science" to regard it in a rational way. We must not, however, assume that the idea of flight was new or particularly a product of thirteenth-century thought, for, as has been shown, it was of great antiquity.

Reverting to mediæval tales of flight we find a much-quoted story—that of Giovanni Baptista (Battista) Danti, a mathematician of Perugia, who about 1490, it is said, flew on more than one occasion over Lake Trasimeno in Umbria. The tradition appears to be based on a genuine attempt of some sort, because a description exists of an apparatus used.† It is true that the account containing this description was published nearly two hundred years after the alleged flights took place, but it may, nevertheless be regarded as evidence that a contrivance was contemplated, if not constructed, for the purpose of flight. The contrivance consisted, it is said, of wings constructed proportionate to the weight of the operator's body, and there is mention of an iron stay of the left wing which collapsing caused Danti to fall after he had successfully launched himself and flown three hundred paces from the top of a tower in Perugia. The alleged flights over Lake Trasimeno, which are more traditional than circumstantial in character, must have antedated this attempt because Danti is stated to have injured himself severely in the fall

* "De mirabili potestate Artis et Naturæ, etc." Printed in Paris in 1542.

† Crispolti, C., "Perugia Augusta," 1648; also Boffito, G., "Il volo in Italia," 1721.

and it may be assumed that it was his final effort. A reference to the working of the contrivance " with a horrible hissing sound " has been interpreted as indicating that it was of the ornithopter or flapping-wing type and possibly an imitation of one of those designed by Leonardo da Vinci at about the same time. Alternatively, the contrivance has been regarded as a genuine attempt to construct some sort of glider or stationary-wing machine—but the evidence appears inadequate to support either view, and there remains only a justification for the belief that the story has an essential basis of truth.

It is important to a proper understanding of the history of mechanical flight and particularly to the phase we are now entering upon that we should consider briefly the state of science in the fifteenth century—the beginning of that period which is termed the Renaissance. The revival of learning, which began in Italy early in the fifteenth century, spread all over Europe taking a different course in each country but finding its ultimate expression, in so far as mechanical science is concerned, in the philosophy of the approach to knowledge by experiment—the method of experiment advocated by Roger Bacon. At its inception the movement aimed at the reconciliation of knowledge with dogma, but what we should now term scientific knowledge was little affected. Art and literature fell more under the influence of the revival, and science, touched last, found its development not as a result of abstract research but as the outcome of the practical needs of the age. It consisted in the application of known principles to problems such as military engineering, navigation and architecture. Hence, in the fifteenth century, the era of true experimental and mechanical science had not begun; the study of dynamics was almost unknown and in the field of statics little progress had been made since the period of Aristotle and Archimedes. In regard to technological devices the position was somewhat different and there appears to have been a certain established tradition. Progress in the experimental sciences depended largely on the development of instruments of precision as an aid to accuracy in measurement. The development of instruments in connexion with such subjects as astronomy, navigation, surveying and the calculation of time had been undertaken, but it was a comparatively narrow field, and in that of mechanical science—as already observed—little progress had been made. It is thus all the more astonishing that an attempt on scientific lines should have been made to consider the possibility of human flight by mechanical means—it was an assault on Nature of profound significance.

Leonardo da Vinci (1452–1519), who is acclaimed as the " universal genius " and as a philosopher whose range exceeded that of any contemporary, was the first to record some rational principles of human flight, and it may be said that the age of true scientific speculation on the subject began in the fifteenth century with his advent. When considering the possible effects of Leonardo's work in aeronautics it must be borne in mind that the results of his investigations were not made known to the world until 1797, when his manuscripts were first described—Napoleon having caused them to be brought to Paris from Italy during the previous year.* It is clear, therefore, that Leonardo's research could not have really influenced investigators prior to 1797, though it is possible that his work was known to a few of his contemporaries.

His main contribution to the subject of flight is contained in his note-

* The first serious discussion of the MSS. dealing with scientific matters was contained in " Essai sur les ouvrages physico-mathématique de Leonardo da Vinci," J. B. Venturi, 1797, but the " Codice sul volo degli Uccelli, e varie Altre Materie " was not published until 1893.

book " Sul volo degli Uccelli " (On the Flight of Birds), written at Florence in 1505. The fundamental idea underlying his investigations, and guiding him in the course of his observations, was that human flight could be accomplished by the mechanical imitation of nature and that a close study of bird flight would reveal the basic principles. With this end in view he made what must have been very long-continued and careful observations of bird flight and, indeed, scientific observations in the whole field of natural flight. His approach to the subject was in itself illuminating; he wrote in another manuscript: " I have divided the treatise on birds into four books; the first treats of their flight by beating their wings; the second treats of flight without beating their wings and with the help of the wind; the third treats of flight in general, such as that of birds, bats, fishes, animals and insects; the last of the mechanism of this movement."*

The distinction between flapping-wing flight and gliding flight is signficant and he continues: " To speak of this subject you must explain in the first book the nature of the resistance of the air, in the second the anatomy of the bird and of its wings, in the third the method of working the wings in their various movements, in the fourth the power of the wings and of the tail at such times as the wings are not being moved and the wind is favourable to serve as a guide in different movements."

That Leonardo recognized the fundamental character of the centre of gravity is clear, for he says: " . . . mechanical science is very noble and useful beyond all others, for by its means all animated bodies which have movement perform their operations; which movement proceeds from their centre of gravity. This is situated at the centre, except with unequal weight." He made a sketch of a bird suspended by a cord over pulleys and explained that this was done to determine the centre of gravity of the bird. Further, he realized the relation between the centre of pressure and the centre of gravity in the maintenance of equilibrium in flight, for he wrote: " All bodies which do not bend, whatever their size or weight, exert equal pressures on all the supports that are equi-distant from the centre of gravity, this centre being at the middle of the substance of such a body."

A detailed analysis of the methods of bird flight follows. It is clear that although Leonardo devoted much of his manuscripts to a consideration of flapping-wing flight and based his designs for flying machines on that principle, he appreciated fully the fact that in nature there is an alternative method, *i.e.* the method of gliding flight. In this connexion he considered the flight of the kite and of other birds when soaring in ascending air currents and he suggested how the various forces were balanced. Further, he understood the purpose of curvature in a bird's wing and, even more remarkable, he appears to have comprehended something of the air flow over such a wing. He drew attention to the need for research in the medium in which flight is undertaken, realizing that the true explanation of the phenomenon could be found only when a knowledge of the air and its currents had been obtained on the analogy of the movement and flow of water.

It will be seen that Leonardo regarded the problem in a truly scientific spirit; he observed and studied the animals who were capable of flight, their anatomy and their movements under different conditions, and also the medium

* This and other translations are taken from " The Mechanical Investigations of Leonardo da Vinci," by Ivor N. Hart, 1925.

in which they operate. He searched for the cause of every observed effect, and from his deductions he made a statement of basic principles—a simple statement of the law of reactions as applied to flight—which is unique in that it is the first. Thus: " An object offers as much resistance to the air as the air does to the object." And again: " The air has greater density when near to water and greater rarity when nearer to the cold region." These extracts in their conciseness gave some indication of the range and accuracy of his work—a composition which it is impossible to do justice to within the limits of this brief survey.

In addition to his statement of principles, Leonardo made two contributions to the science of aeronautics which may be regarded as wholly inventive in that there is no conclusive evidence that the underlying principles were earlier applied. He invented the parachute and the helicopter, illustrating the function of each in his notebooks. As already observed, the latter represents the first *known* application of the screw, or helix, for use in the air. There is also some evidence to suggest that he invented, or at least anticipated, the invention of the balloon, for it is recorded that he made " figures " of thin wax which when filled with warm air rose in the air.* If this was indeed the case, Leonardo anticipated the invention of the hot-air balloon, or Montgolfière, which took place in 1783, but there is no corroborative evidence of these experiments. Further, the statement from another source that Leonardo actually made an attempt to fly by mechanical means, but without success, lacks confirmation, and we must rely solely on the evidence of the notebooks as a record of his achievements.

The idea of flight by imitation of nature, which during this period appears to have emanated from Italy and found expression in the exploits of Danti and the research of Leonardo, has a further illustration in the attempt attributed to John Damian in 1507. It is of course possible that this and the attempt of Danti were both inspired by some knowledge of Leonardo's work and the fact that the earlier exploit is said to have occurred in 1490. in which year Leonardo is known to have begun to record his observations, is a coincidence worth noting.

Damian, who was also an Italian, came to Edinburgh from France in 1501 and was appointed to the Scottish Court of James IV as physician to the king's household. He appears to have been an ingenious person, both in gaining the confidence of the king and in securing grants of money for various experiments in alchemy. Moreover, the abbacy of Tungland was actually conferred on him, though he seems to have had no previous connexion with the church. His alleged attempt to fly was made during 1507, and the circumstances are described in the " History of Scotland," by John Lesley (Bishop of Ross), written about 1570. Apparently he constructed wings made of feathers, which being fastened to his body he tried to launch himself from the castle wall of Stirling, but soon fell to the ground, breaking a thigh-bone. Lesley remarks—on what authority it is not clear—that the adventure was an attempt to outdo the traditional exploit of King Bladud, and the suggestion that the inspiration came from that legend is thus unavoidable. It is probable, however, that Damian, though he was clearly an adventurer, had some conviction as to the possibility of flight, else he would not have risked his life and reputation in the attempt.

* Vasari, " Lives of the Painters," 1550.

It has been seen, from the few examples cited, that the early attempts to fly were abortive; they were merely foolhardy leaps into an unknown element which in all cases ended in injury or death. On the other hand there was vague speculation and theorizing of a more serious sort, which was a genuine endeavour to comprehend the underlying principles. The research of Leonardo da Vinci falls within the second category and he was followed, a century later, by an Englishman, John Wilkins (1614–1672), Bishop of Chester, and first secretary of the Royal Society on its revival in 1660, whose writings are among the earliest printed works in which the subject of flight is considered and discussed as a scientific problem. These writings, which appeared first as a discourse published in 1640 and more fully in his "Mathematicall Magick" (first edition 1648), have been regarded more as a résumé of the ideas of previous investigators than as an original inquiry into the subject, owing perhaps to the fact that he discusses in detail at the outset the legends of Archytas and Regiomontanus. The fact that Wilkins considered these and other legends and examined the evidence closely, shows that he approached the subject in a proper spirit—that of an impartial inquirer—and a more scientific atmosphere is apparent. The chapters dealing with flight are found in the second part of "Mathematicall Magick," which is entitled "Dædalus, or Mechanicall Motions." Chapter VI deals with "volant Automata" and contains the discussion of Archytas' "dove" and the "eagle" of Regiomontanus, concluding with a consideration of the "possibility and great usefulness of such inventions." There is a reference to the primitive attitude that men "should not, in any particular, endeavour to transgress the bounds of nature," and "since we are naturally destitute of wings, not to imitate the flight of birds." Wilkins suggests that here is the reason why there is so little (of a rational nature) in ancient writings on the subject of human flight: "The Ancients durst not so much as mention the art of flying but in a fable." There is probably truth in this statement and, if so, it explains why, for so many centuries, the problem was shrouded in mystery. Even Wilkins was not free from the symbolism of an earlier age, as his use of the word "magick" shows.

The next chapter deals with the "art of flying" and "the several ways whereby this hath or may be attempted." Note that he infers nothing more than an "attempt," and he classifies the methods whereby such attempts have been or may be made. They are:

1. By spirits or angels.
2. By the help of fowls.
3. By wings fastened immediately to the body.
4. By a flying chariot.

The first method is illustrated by examples from classical literature and the second by fictional projects. There is no question—as has been sometimes suggested—that Wilkins considered these as possible methods; he is simply classifying under convenient headings. In regard to the use of wings fixed to the body he is also reserved, but points out that frequent trial and exercise are essential to success in matters of this kind; constant practice is necessary. He cites the use of wings used "at a running pace" whereby the operator was able to "step constantly ten yards at a time." He maintains that "it is not more incredible that frequent practice and custom should enable a man for this." We may regard these remarks as merely sober comment and not very constructive, but we shall see that they represent fairly the

attitude of the most notable of pioneers—the Wright brothers—some 250 years later when, after consideration of all that had previously been advanced, they came to the conclusion that actual practice (with artificial supporting surfaces) in the air was essential to any success—was in fact fundamental as the basis of any knowledge to be obtained.

To the fourth method—that of a flying chariot—Wilkins gives closest consideration. It seems to him " altogether as probable, and much more useful than any of the rest." He devotes a final chapter to the subject and immediately raises two queries: (1) " Whether an engine [the instrument used to effect a purpose] of such capacity and weight, may be supported by so thin and light a body as the air "; and (2) " Whether the strength of the persons within it, may be sufficient for the motion of it." In answer to the first he states that " the engine can never be too big or too heavy, if the space which it possesses in the air, and the motive faculty in the instrument be answerable to its weight." This conclusion was wholly logical when based on the analogy of a body floating in water (which Wilkins cites a little later). and is a true exposition of the lighter than air principle of flight. It is also true as regards an apparatus heavier than air (as further knowledge showed) if the " motive faculty " is " answerable to its weight." It is difficult to see how Wilkins could have stated this conclusion better, bearing in mind the phraseology of his time.*

In answer to the second query, though he knows that " there may be some bodies of so great a bigness, and gravity, that it is very difficult to apply so much force unto any particular instrument, as shall be able to move them," he will admit only " that it is very difficult to contrive any such motive power, as shall be answerable to the greatness and weight of such an instrument . . . ", which does not " impair the truth to be maintained." He cites the gliding flight of the Kite as an example of a fine performance made often " without the help of any strong forcible wind " and maintains that " when all the due proportions in such an engine are found out, and when men by long practise have arrived to any skill and experience, they will be able in this (as well as in many other things) to come near unto the imitation of nature."

This was a reasoned statement of the problem; it drew attention to the phenomenon of natural gliding flight as the basis for investigation; it gave, as conclusively as was possible at that time, the arguments in favour of success, and it was made by a man of considerable eminence in the scientific world whose writings must have been widely read. The work of Bishop Wilkins, in this regard, deserves fuller consideration by the student of aeronautical history than it has heretofore received.

The final consideration in these brief notes on early speculation and the imitation of nature must be on the work of the Neapolitan Giovanni Alphonso Borelli (1608–1679) whose critical treatise " De Motu Animalium " was published in Rome in 1680. The effect of this work, though discouraging to contemporaries, was salutary and it was a notable contribution to the early literature of aeronautics. Borelli's treatise contained a reasoned analysis of the mechanical action of the limbs of birds and animals. In particular, one part, " De Volatu," dealt with the flight of birds, which he considered in a manner somewhat similar to that of Leonardo, of whose writings he must,

* All the quotations here made are from the first edition (1648); other editions appear to differ only in punctuation.

however, have been ignorant, and more especially with flapping-wing flight. The importance and value of his work lay in the scientific arguments which he advanced against the possibility of flapping-wing flight by man unaided—arguments based on the fact that the pectoral muscles in man are very much less in proportion to the total weight than in birds, which definitely refuted the contention that such flight might be possible and exposed a fallacy which, nevertheless, recurred for centuries, and is, even to-day, held by some. Borelli summed up his conclusions by stating that " it is impossible that men should be able to fly craftily by their own strength "—*i.e.* by the exertion of effort in flapping artificial wings. There is little doubt that his statement was not at first wholly accepted, but it was a weighty contribution which represents an important stage in the progressive accumulation of knowledge.

What then was the state of knowledge at the close of the seventeenth century? It was such as to discredit the idea of artificial flight by means of flapping wings—the idea had been refuted both in theory and by experiment—nevertheless experiments on those lines persisted and have continued even to the present day. The capabilities of rigid planes were not understood—though the phenomenon of gliding flight had to some extent been investigated—and a prime mover which might enable such planes to derive support from the air was an invention of the distant future. It is thus understandable that the eighteenth century was almost devoid of actual experiment in regard to mechanical flight, and that, when an alternative method of aerial navigation presented itself, it was eagerly grasped and exploited.

V. THE LIGHTER-THAN-AIR PRINCIPLE REVEALED

1670–1782

IT HAS BEEN SEEN that the earliest speculations in regard to flight were based on imitation of the natural flight of birds; that, is, flight by bodies heavier than air. The alternative method of ascent in the air by means of apparatus lighter than that element has no obvious counterpart in nature and its practical introduction resulted from the growth of knowledge concerning the nature of air and of other gases. It is interesting, however, to attempt to trace the origin of the conception of a vessel buoyant in the air, which came long before the knowledge which enabled it to be carried out successfully.

The conception of a ship sailing over the "aerial ocean" (the sky being conceived as such an ocean) figures in the mythology of India, but it seems doubtful whether such ships were imagined as lighter than the element in which they were to move, because in some cases they are described as being fitted with wings and in others as being drawn by animals such as horses and goats instead of the more appropriate eagle or swan. A primitive conception of the sun as a boat navigating the atmosphere occurs also in mythology, but it is hardly worth examination in this connexion. In the "Arabian Nights," Jinn rise by swallowing air, and it is possible that, underlying the conception, there was an appreciation of the fact that heated air is lighter than cold air. Air swallowed by the fiery Jinn would be raised somewhat in temperature above that of the atmosphere.

The conception of a vessel light enough to float in the air was, of course, in accordance with the law of Archimedes (*c.* 250 B.C.) relating to the flotation of bodies in liquids or gases—a law which was known to savants during the Middle Ages—and it should be regarded as having arisen from that knowledge. It has been stated that Roger Bacon defined such a vessel, but though he may have been aware of the Archimedean law, no passage in his writings containing a definition or formula for a lighter-than-air apparatus can be traced.

It appears that in the fourteenth century the question was considered, notably by Albert of Saxony who maintained that the air could be navigated to some extent by flotation, and by Leonardo da Vinci, who, according to Vasari, experimented with wax figures filled with warm air, but it was not until the seventeenth century that a revival of the idea led to its actual formulation. We find again that speculation in regard to flight (by this new method) is evidenced in Italy, perhaps due to the realization of the impossibility of success by the imitation of nature, to which Borelli had so aptly contributed. It is understandable that such a realization should have tended to divert attention to the only other method of flight which was conceivable. The revival there is marked particularly by the speculation of Francesco di Mendoza who died in 1626, and by the Jesuit physicist Gaspar Schott, or Schottus, (1608–1666).

The analogy of bodies heavier than water being able to float thereon when filled with air was cited by di Mendoza, and apparently he went so far as to suggest that a wooden vessel, or one of other material, when filled with "elementary fire" could be sustained under certain conditions. The element

of fire, it should be noted, was considered by several at this period as a possible medium whereby a vessel might be sustained in the air and therefore propelled by oars. It is interesting also to note that this particular consideration of the lighter-than-air principle was made some years ago before Borelli's critical work appeared, and thus it cannot be regarded as a result of the discouragement in the imitation of nature contained in that work. Schott, who it seems had a high reputation for his knowledge of the physical sciences, went further than did di Mendoza, for he asserted his firm belief that substances of greater specific gravity than air could be made to float therein. The matter is discussed in his "Magia Universalis," but without any significant addition to the bulk of known or supposed fact.

Mediæval thought on this subject appears to have been concerned solely with the consideration of fire or solar heat as a means to flotation in the air, and it is explained by the lack, at that time, of any exact knowledge of gases lighter than air. An egg-shell seems to have provided the best example of a vessel suitable for flotation in the atmosphere, being extremely light, and proposals were even made to fill such shells with water vapour, when, on exposure to solar rays, it was assumed that they would rise in the manner of dew from the grass in early morning! The idea of flotation in the air as a possible means to locomotion in that element was not confined to the revival in Italy for we find that John Wilkins refers to it in "Mathematicall Magick" (1648), where he makes a statement of the lighter-than-air principle based on the "subtle science" of Archimedes. Concerning bodies carried in the air he says: "It is not their greatness (though never so immense) that can hinder their being supported in that light element, if we suppose them to be extended into a proper space of air." He declares that "it is possible to raise a new science, concerning the extension of bodies, in comparison to the air, and motive faculties by which they are to be carried." This was, of course, theoretically true, but Wilkins made no attempt to show how it could be attained.

In 1670, however, a proposal (the first properly formulated proposal) for a lighter-than-air aircraft was made by the Jesuit priest Francesco de Lana-Terzi (1631-1687). It will be appreciated that there are two methods whereby a vessel may be rendered lighter than air; one by reducing the air density in it, and the other by displacing the air in it by a gas which is lighter than air. De Lana's project was based on the former method, and, as will be seen later, the first human ascent in the air was accomplished by such means. The proposal for a "flying boat" is contained in his scientific treatise "Prodromo,"* 1670, and it caused much discussion among the learned during the remainder of the seventeenth century. The vessel, which was fully described and illustrated, was intended to float in the air by virtue of the displacement of four large copper globes from which the air had been wholly, or in part, evacuated. It was to be propelled by a sail, and the use of oars was also considered. De Lana had conducted some reasoned experiments in order to determine the weight of air. He had fitted a glass bottle with a stopcock and weighed it, subsequently heating the bottle and closing the stopcock and again weighing it when cool to ascertain the loss due to rarefication of the air under heat. He also immersed the container in water and measured the volume of water which entered, in order to determine what percentage of air

* De Lana. "Prodromo overo saggio di alcune inventioni nuove premesso all' Arte Maestra, etc.," Brescia, 1670.

had been expelled. His final conclusion was that the weight of water, compared with that of air, was as 640 : 1—a figure only slightly in excess of that since established, indicating that his research was by no means negligible. The operation of expelling air by heating the container and thus reducing the air density in it was apparently originated by de Lana, but the full significance of the operation was, it seems, overlooked by him and others until, in 1783, the brothers Montgolfier applied the same method with immediate success.

It will be appreciated that the theoretical reasoning which formed the basis of de Lana's project was perfectly sound, but that the machine as designed would be wholly impracticable because the copper globes would be unable to resist the external atmospheric pressure when any appreciable amount of air within had been withdrawn. He calculated the displacement of each globe should be 4,189 cu. ft., giving a total of 16,756 cu. ft., and, as the area of each globe was to be 1,256 sq. ft. (diameter 20 ft.), their thickness could be only about 0.004 in. De Lana was aware that the atmospheric pressure on the globes would be considerable (actually it would have amounted to several million pounds), but he appears to have thought that it would serve in some way to consolidate them, thus enabling them to retain their shape. He made no attempt to construct the " flying boat "; not, it seems, because he had any lack of confidence in it, but—and this is significant— because he believed, on reflection, that any endeavour to navigate the air would be prevented by the Creator as inimical to civil government and peace! Certainly the most interesting speculation contained in the " Prodromo " is that which relates to and explains that belief. De Lana foresaw and described the use of aircraft for military purposes; the transport and landing of troops by air; the bombing of cities, building and ships. He wrote: " God would not suffer such an invention to take effect, by reason of the disturbance it would cause to the civil government of men. For who sees not that no city can be secure against attack, since our Ship may at any time be placed directly over it, and descending down may discharge Souldiers; that the same would happen to private Houses, and Ships on the Sea: for our Ship descending out of the Air to the Sails of Sea-Ships . . . it may over-set them, kill their men, burn their Ships by artificial Fire-works and Fire-balls. And this they may do not only to Ships but to great Buildings, Castles, Cities, with such security that they which cast these things down from a height out of Gun-shot, cannot on the other side be offended by those from below."*

This was the first suggestion of the use of aircraft in warfare, and though theoretical, it was a remarkable prophecy. Incidentally, we find much the same sentiments expressed 265 years later by a minister of H.M. Government, who delcared: " I wish for many reasons flying had never been invented . . . somehow we have got to Christianize it."†

De Lana's project, as already remarked, caused widespread discussion among the learned, both in his own land and abroad. The impracticability of making globes of sufficient size and lightness, combined with the strength necessary to withstand atmospheric pressure when evacuated, in order to render them buoyant and capable of supporting a boat, was pointed out by Robert Hooke, Borelli, Leibnitz and others, though the proposal found also

* From the first English translation by Robert Hooke (1635-1703) in the " Philosophical Collections," 1679, No. 1, p. 18. The " Prodromo," in the whole original, is also in the Library of the B.M.

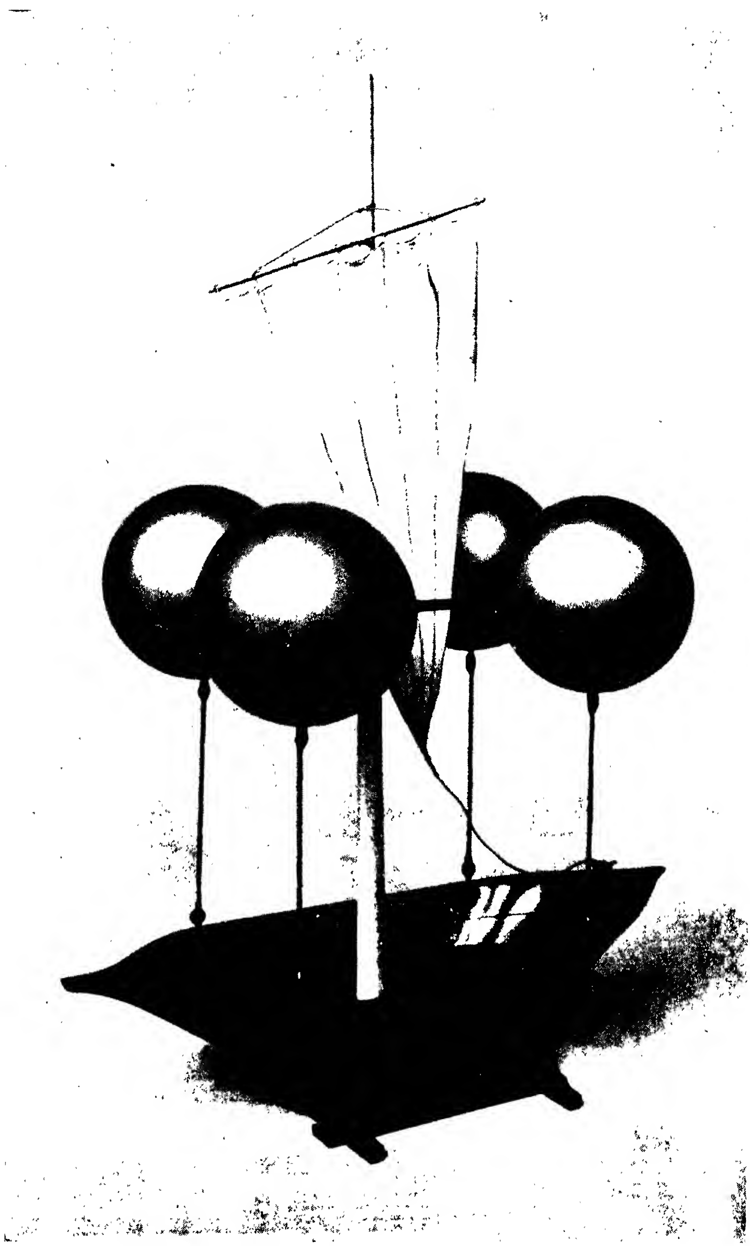
† Mr. Stanley Baldwin as reported in *The Times*, March 24, 1935.

a few defenders. Its historical importance lies in the fact that it disseminated the idea of constructing a vessel which could float in the air, and it served as an inspiration which, from the amount of comment it received, must have been widespread (see Plate IV).

Several proposals for aerial machines on the lighter-than-air principle followed, but they were based generally on the earlier assumption that the rarefied air of the upper atmosphere could in some way be collected and used as a lifting agent. Among those who made such a proposal was the Dominican friar Joseph Galien (1699–1762), Professor of Philosophy and Theology at the University of Avignon, who was not, apparently, deterred by the moral considerations of de Lana. The proposal was typical of mediæval thought; the calculations regarding weight, capacity, displacement and lifting power being elaborate and voluminous, and the conception on a most generous scale. It seems that the Ark of Noah served as the basis for the calculations, but the proposed vessel surpassed the Ark in that its accommodation would be some ten times greater. The speculations of Galien* serve to show, above all, the total failure to appreciate at that time the practical difficulties involved in aerial navigation. Thus, even if a principle had been clearly established—such as the discovery of a gas lighter than air—it is doubtful whether it would have been successfully applied. For instance, most of the projects of the seventeenth century were shown as being propelled by a sail; sometimes the use of oars was considered. The fallacy of the proposal to use sails for the propulsion of a vessel which was to move wholly in one element was not, it seems, apparent at that time.

In order to appreciate the true position at this period of the "new science" (of flight) declared possible by Wilkins, it is desirable to consider only the work of the outstanding investigators, because so much was advanced of a purely speculative and primitive character that an examination of all written on the subject would not be profitable. We may regard Wilkins, Hooke, Borelli and de Lana as expressing the best scientific thought of their time on this subject. Wilkins, as already described, held that mechanical flight was possible, and also the new science "concerning the extension of bodies in comparison to the air." His writings were widely read, and his eminence and position as Secretary of the Royal Society must have encouraged the acceptance of his opinions and stimulated further thought on the matter. His contemporary and friend Robert Hooke (1635–1703), who followed him later as Secretary of the Royal Society, also investigated the subject of flight in its mechanical and practical aspects. As already stated, he translated that part of de Lana's treatise which deals with the flying boat project and he demonstrated its impracticability. He undertook himself some experiments, and in 1655 recorded that he had made a model "which, by the help of springs and wings, rais'd and sustain'd itself in the air." This was, apparently, on the ornithopter principle, but Hooke seems to have abandoned it when he became convinced (probably as the result of Borelli's treatise) that the muscles of a man's body were not sufficient to achieve success in that manner. In a comment on Hooke's "Posthumous Works" (1705) there is mention of "horizontal vanes plac'd a little aslope to the wind" and rotated about a vertical axis—apparently an experiment in lifting by airscrew. Hooke left nothing which can be regarded as a definite contribution, bearing in mind

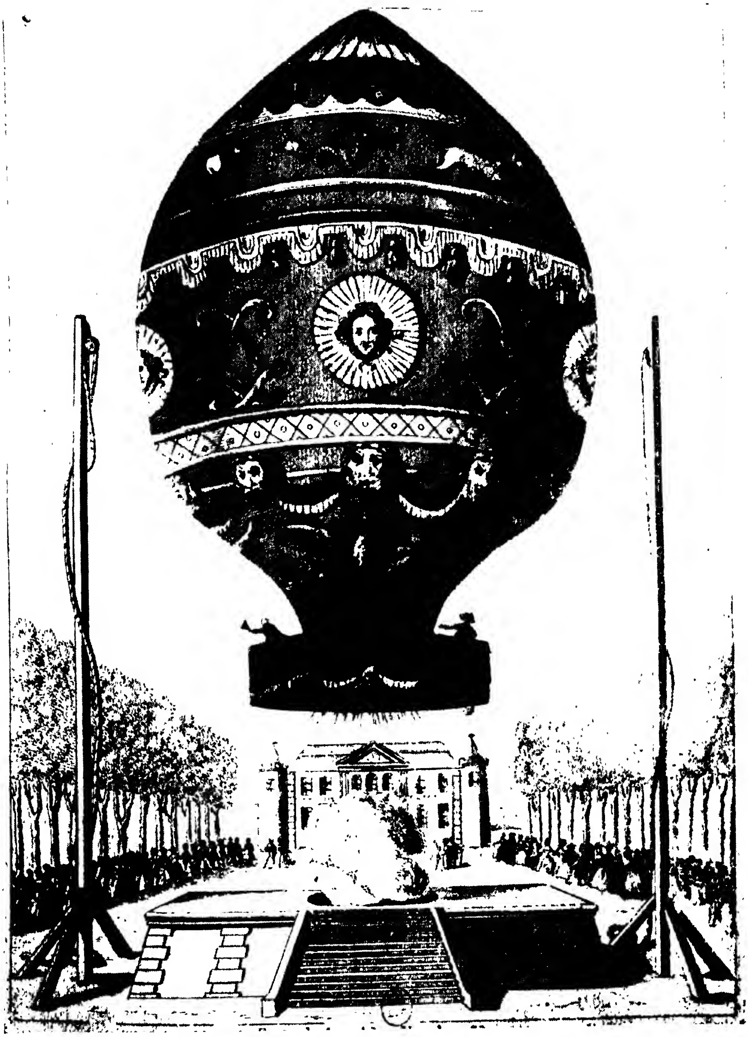
* Galien "L'Art de Naviger dans Les Airs," Avignon, 1755.



Francesco de Lana's Proposed Aerial Vessel, 1670

The first properly formulated proposal for a lighter-than-air vessel a conception sound in principle but impracticable in execution (See Page 24)

PLATE V



Ascent of Pilâtre de Rozier and the Marquis d'Arlandes from the Château de la Muette, November 21, 1783

This, the first aerial voyage in history, was accomplished in a Montgolfière or hot-air balloon and lasted twenty-five minutes (*See Page* 30)

what had already been advanced, but his attitude to the subject was new in that he examined it in a more critical manner.

The work, in Italy, of Borelli, has already been described. He also pointed out the impossibility of de Lana's project. The two minds were opposite in their characteristics; the one critical and (rightly) destructive, appreciating the practical difficulties, the other creative but lacking the judgment which could test his conceptions. De Lana is rightly regarded as having laid down the fundamental principle of the balloon and airship. His supposition that air has weight, that a vessel could be exhausted of all or a part of the air contained in it, and that when a body is lighter than another it will ascend in the heavier body if that is a liquid, shows that he foresaw and understood the principle of lighter-than-air flight—the principle was definitely revealed. This was at a time when the cumulative effect of repeated failures to accomplish flight by the method of imitating nature, and the discouragement resulting from Borelli's writings, had encouraged an attitude of doubt that success would ever be achieved. This scepticism found expression in brilliant satire such as that of Joseph Addison in 1713,* and in much critical writing. In fact the attitude of incredulity and of ridicule, at least in regard to mechanical flight, lasted over two centuries and, as will be seen later, it was not until about the year 1908 that the possibility of heavier-than-air flight was universally recognized.

It was nearly a century after de Lana's proposal before the next stage in the development of lighter-than-air vessels was reached, and that stage did not lead to an immediate advance towards the art of "aerial navigation," as it was subsequently called, because it was a discovery the full significance of which was not at once realized. The discovery was the recognition of the fact that hydrogen was a gas very much lighter than air, in fact the lightest gas known, and it was made in 1766 by the distinguished chemist Henry Cavendish (1731–1810). As an outcome of earlier investigations into the nature of air and other gases made by Boyle, Stahl, Black, Lavoisier and others, and as a result of his own experiments, Cavendish was able to isolate definitely the gas hydrogen, the existence of which had been known previously, but the properties of which had not been determined. His discovery was essentially the determination of the weight, or specific gravity, of hydrogen, or "inflammable air" as it was then commonly termed. Hydrogen had been known as a combustible component of air since about the middle of the seventeenth century, and it is said that Boyle produced it but without realizing that he had done so. Cavendish was able to collect a sufficient quantity of the gas, for the purpose of his research, by pouring sulphuric acid over iron filings, and his discovery of its small weight in relation to that of air was destined to provide a means of inflating a spherical container in such a way that its displacement would be sufficient to raise and support it.

The extreme lightness of the gas was at once perceived to be its outstanding characteristic, but this was not apparently at first regarded as of any particular significance by Cavendish, who was not concerned with the problem of lighter-than-air flight and was not seeking a solution to it. Certainly he made no suggestion that it might be applied for aerial navigation, though he was aware that it could be obtained in large quantities by chemical

* Contributed to the *Guardian*, 1713, in a letter signed "Dædalus." The facetious suggestion that "the roads of England will be saved" (by aerial travel) contained more wisdom than satire.

processes. As so frequently happens, the results of a research were not applied by the investigator, and it remained to others to propose the obvious application. This was done in 1768 or 1769 by the chemist Joseph Black (1728–1799), who suggested that if a sufficiently thin and light bladder was filled with "inflammable air," the bladder and the gas contained therein would constitute a mass lighter than the same bulk of atmospheric air and would rise in it. Black went so far as to consider having the allantois of a calf prepared with a view to making such an experiment, but the experiment was never, it seems, made owing to his being otherwise engaged, and he referred to it later in correspondence as something which he had contemplated as "merely amusing."*

Tiberius Cavallo (1749–1809), who has already been mentioned in connexion with the interpretation of the early legends of flight, refers to this proposal in his "History and Practice of Aerostation" (1785), and also to some experiments which he had made in regard to the construction of a vessel which, when filled with hydrogen, would ascend in the air; this account of his research had previously formed the subject of a paper read before the Royal Society.† He describes how he considered the use of paper to make a "vessel, or sort of bag," which, when inflated with hydrogen, would ascend in the air. Later he tried animal bladders of different sorts, but, in all cases, he found that for their size they were too heavy. Other substances were considered, but as Cavallo says, "... the only success I had, was to let soap-balls [bubbles], filled with inflammable air, ascend by themselves rapidly into the atmosphere; which was perhaps the first sort of inflammable-air balloons ever made." This was in 1781, apparently, and it was the first demonstration of the use of gas as a lifting agent. There is little doubt that the experiments were prompted by the suggestions made by Black in the course of his lectures some fifteen years earlier.‡

It may be accepted that by this time (1781-1782) the possibilities of hydrogen as a lifting agent for lighter-than-air vessels were well appreciated by those who had seriously considered the question, but it remained for some-one to discover a suitable material to form a container which would obviously have to be both light and gas-tight. As in the case of many other inventions, development was delayed (though in this case not for long) because suitable materials were not readily available. It was upon the solution of this particular problem—that of making a suitable container for the lifting agent—that successful aerial navigation by means of lighter-than-air aircraft depended. The solution came in 1783 when the first human ascent in a hydrogen balloon—the first practical vehicle of the air—was accomplished, but, just prior to that achievement, the idea of human ascent was realized in another type of lighter-than-air aircraft, namely, the Montgolfière or hot-air balloon. This invention, which in strict chronology comes first, did not prove to be of any enduring practical value; nevertheless it was the first balloon and it will be dealt with in that order. The principle underlying it was that clearly demonstrated by de Lana in the course of his experiments in regard to the weight of air.

* Black described his original proposal in a letter dated November 13, 1784, published in the "History and Practice of Aerostation," 1785, by Tiberius Cavallo.

† On June 20, 1782. The experiments with soap-bubbles were also recorded in Cavallo's "Treatise on the Nature and Properties of Air," 1781.

‡ The most comprehensive account of the work of the eighteenth century chemists with regard to the discovery of hydrogen and its suggested application for aerial navigation, is contained in "The History of Aeronautics in Great Britain," by J. E. Hodgson, 1924.

VI. INVENTION OF THE BALLOON

(*First Great Period of Achievement*)

1783–1800

THE INVENTION OF THE BALLOON marks the first great period of achievement in regard to aerial navigation. When we consider it in detail we seek, perhaps unconsciously, for an explanation of the psychology of inventive genius as it was then applied, but nothing tangible results. The principle of the balloon was, as we have already seen, satisfactorily defined in England by Wilkins (1648), and it was formulated in Italy by de Lana (1670). The gas, hydrogen, which made it a practical possibility, was discovered in England by Cavendish (1766), and its application for lifting purposes was later suggested in this country. It is reasonable to suppose that the final problem, that of making a suitable container for the gas as a lifting agent, would have been solved in the country of its origin, but it was not so. There was not, apparently, anyone sufficiently optimistic—probably most important in the psychology of invention—to explore the matter further at that time.

The balloon was invented in France and, surprisingly, was not first conceived as a direct result of the discovery of hydrogen, but quite independently as the outcome of private experiments of a simple character. The brothers Joseph Michel (1740–1810) and Etienne Jacques (1745–1799) Montgolfier, who were paper-makers of Annonay, near Lyons, made no use of the accumulated knowledge concerning hydrogen when they began to consider in 1782 the construction of a lighter-than-air (aerostatic) machine. Apparently they were either unaware of the qualities, or failed to appreciate its value as a lifting agent, because their experiments were not in any way connected with it. The brothers appear to have drawn their inspiration direct from nature, for as Cavallo remarks: " The natural ascension of the smoke and the clouds in the atmosphere suggested the first idea; and to imitate those bodies, or to enclose a cloud in a bag, and let the latter be lifted up by the buoyancy of the former, was the first project of those celebrated gentlemen." This may be taken as a fair explanation of their original idea, and it is borne out by other evidence. Some writers have referred to the brothers gazing at smoke rising from their domestic hearth or issuing from a particular chimney at Avignon—a parallel to the traditional episode of James Watt and the domestic kettle—but those detailed incidents lack confirmation.

It must not be forgotten that the research of Robert Boyle (1626–1691) in the effects of temperature on the expansion and contraction of air and in other matters—which marked the rise of modern chemistry—was, at this time (1782), well established, and, with similar work by chemists abroad, may possibly have provided the real inspiration for the invention of the hot-air balloon. We know that the brothers were interested generally in physical phenomena and that they had read Joseph Priestley's " Experiments and Observations on Different Kinds of Air " (French edition, 1776); in fact, Joseph Montgolfier (to whom the major share in the discovery of the balloon

is attributed) is said to have acknowledged an inspiration, "like light in darkness," that aerial navigation was possible, after reading that book.*

In the history of aeronautics, as in the history of most human endeavour, we find remarkable parallels and analogies. The balloon, which will now be described, was invented (in the sense of successfully devised) jointly by two brothers, as the aeroplane was invented 120 years later by two brothers—the Wright brothers. These men were all practical rather than theoretical and they approached the subject as from the beginning—undertaking, in each case, an independent inquiry through their own experiments; they were none of them highly educated in the sense of having specialized in any branch of technology. There is, naturally, evidence of a varying degree of genius, but the circumstances were largely the same, though, of course the Wright brothers' problem was far more abstruse. The total age of the Montgolfier brothers at the time of their invention was seventy-nine years, and that of the Wright brothers sixty-eight years. The benefit derived by the inventors, in both cases, was distinction rather than pecuniary gain.

The period now under review was marked in England by a development which constituted a new page in the world's history. In 1781 James Watt (1736-1819) invented the rotative steam engine; that is, he designed his engine to turn a shaft upon its axis and thus enabled it to drive machinery of all kinds. It was the control of a new power which could be employed anywhere and for almost any purpose independent of the uncertainties of wind or water—probably the greatest individual contribution to the changes in the world's history. In France, it was a decade before Louis XVI relinquished all independence as head of the state by surrendering himself to the care of the Legislative Assembly, thus marking a stage in the history of that movement which we call the French Revolution. The period was one of aspiration for political consolidation, greater individual responsibility and revolt against domination over the consciences of the people—causes of unrest which had been working in most European countries for many centuries. This, then, was the setting for the invention of the balloon, and it explains, to some small extent, its subsequent history.

In November 1782 the elder Montgolfier (doubtless in collaboration with his brother) made the first experiments with small oblong paper bags (*balons*) which he inflated with hot air. Obviously their experience as paper manufacturers aided them in this and the subsequent construction of larger balloons. At Avignon, a little later, they constructed a bag of silk of about 40 cu. ft. capacity and open at the bottom. By burning paper below the opening, the bag was distended and rose to the top of the room where the experiment was being made. Experiments were continued out of doors at Annonay, where a bag ascended to a height of about 70 ft., and another of 650 cu. ft. capacity, when placed above a fire of wool and straw, rose some 600 ft. in the air. It appears that the brothers were unaware, at least at that time, of the true explanation of the phenomenon, attributing it to the supposed lifting power of smoke, hence the fire of wool and straw, which, it is stated, was sometimes damped to produce that effect. Some contemporary accounts of the Montgolfiers' work credited the ascent to the virtue of an unknown gas, the product of the fire of wool and straw employed, and described as "Montgolfier's gas" or *l'air alkalin*. The error persisted, apparently until the

* H. Turnor, in "Astra Castra," 1865.

physicist de Saussure ascribed the lifting power to its proper cause, *i.e.* the rarefaction of heated air. He experimented in 1785 with thermometers placed outside and inside a hot-air balloon and gave definite proof of the falsity of speculation regarding "Montgolfier's gas."

Further experiments were made by the Montgolfier brothers in April 1783, of a private nature, as previously, but they decided that their research was now so far advanced as to permit of a public demonstration, and this was undertaken on June 5, 1783, at Annonay with a spherical balloon of some 24,000 cu. ft. The balloon was constructed of linen the sections of the envelope being joined together by buttons. This was obviously not air-tight and the lifting medium, the heated air, had to be confined by a lining of paper which covered the inside of the linen sections. The ascent took place in the market place and the machine rose to a height of some 6,000 ft., travelling meanwhile a horizontal distance of 7,668 ft. from the starting point.*

This memorable demonstration created much interest among Parisian savants, and enthusiasm throughout Europe generally; an account of it was sent immediately to the French Court. The Académie des Sciences was stimulated to report later on the invention and to initiate work on parallel lines.† Meanwhile, the Montgolfier brothers were proceeding towards their crowning achievement in the accomplishment of human ascent. At Versailles, on September 19, 1783, before Louis XVI and the Court of France, they gained the further distinction of being the first to launch into the air three living animals, a sheep, a cock and a duck, which were caged in a wicker basket suspended beneath the balloon, the object of this experiment being to determine whether a rarefied atmosphere would have any effect on the physiology of those creatures not accustomed to it. The balloon remained in the air for 8 min., finally descending in the forest of Vaucresson some 1½ miles from the point of ascent. The animals passed through the experience quite unhurt save that a wing of the cock was damaged, the injury being attributed to a kick from the sheep. The balloon was decorated in a flamboyant manner characteristic of this and the later Montgolfières.

It should be noted at this stage, in order to avoid confusion in regard to the chronology of events, that the development of the hydrogen balloon was proceeding simultaneously with that of the hot-air balloon—in fact, the first public demonstration with a model of the former took place on August 27, 1783. The invention of the hydrogen balloon and its important function as the precursor of the airship will be described in these notes, but separately from the subject of the hot-air balloon, now being considered, which as will be seen is only incidental to the development of practical lighter-than-air aircraft.

The decoration and reward of the brothers Montgolfier by Louis XVI served as a prelude to their final achievement. Further experiments depended, naturally, on the discovery of some person willing to entrust himself to the balloon; it was at first proposed that two criminals under sentence of death should be sent up, but finally the young technician J. F. Pilâtre de Rozier was permitted to undertake the first human ascent, which took place on October 15, 1783, in an oval Montgolfière having a capacity of 60,00 cu. ft.

* Cavallo. "History and Practice of Aerostation," 1785.
† The Report, signed by several members, was dated December 23, 1783.

The balloon was provided with a wicker gallery attached by cords, and it was held captive during the ascent to a height of some 80 ft., where it was able to remain for nearly 5 min. by repeated stokings of the fire, carried in a brazier slung in the aperture. The intrepid Pilâtre reported that his ascent had been harmless and even exhilarating, and he accomplished several other tethered ascents during the following weeks, sometimes accompanied by a passenger, in preparation for a free flight.

On November 21, 1783, he ascended in the same balloon from the gardens of the Château de la Muette in the Bois de Boulogne with the Marquis d'Arlandes as passenger. The prevailing wind was north-west and it carried the balloon across Paris a distance of over 5½ miles at a height of some 300 ft. The descent was safely accomplished after an aerial voyage lasting 25 min.—the first in history. An incident of the flight—according to the account of the Marquis d'Arlandes— was the extinguishing of a fire in the fabric of the balloon by means of a sponge and water carried for the purpose. This Montgolfière was elaborately decorated, the circumference being surrounded with the fleur-de-lis in gold and with plaques representing the head of the king. The signs of the zodiac encircled the upper portion and flamboyant decoration covered the gallery beneath. The colour was a deep azure with crimson and gold embellishments (see Plate V).

It will readily be understood that the hot-air balloon was not a really practical air vessel in that it had a very limited endurance dependent upon the maintenance of the fire. The danger from carrying an open fire was considerable, and the limitations in regard to lift led to an increase in size which was obviously undesirable. However, many notable ascents were made, including one at Lyons on January 19, 1784, when seven persons were carried in a Montgolfière having a capacity of 560,000 cu. ft.

It was inevitable that the hot-air balloon with its dangers, limitations and constructional difficulties, should be superseded by the hydrogen balloon immediately the latter had been developed as a practical vehicle of the air. In a few years there remained only recollections of the gaudily decorated Montgolfières and the record of the courageous and ever-memorable first ascents. The spectacle of such ascents must, indeed, have been fearsome. Dense clouds of smoke issued from the neck of the balloon as a result of the fuel used, and there was the ever-present threat of fire. There are a number of contemporary engravings representing the historic ascents of Montgolfier balloons. As in the case of much draughtmanship of that period, the details of decoration and form vary considerably.* Probably the most authentic representation is that on an original copper plate in the collection of M. Charles Dollfus.

We pass now to the development of the hydrogen balloon. The discovery of the weight of hydrogen by Cavendish in 1766 has already been referred to, and the earliest experiments made with a view to its application as a lifting agent for lighter-than-air aircraft. It appears that calculations made in 1783 by members of the Académie des Sciences indicated that the supposed "Montgolfier's gas," which was thought to produce the ascent of the hot-air balloon, was only about half the weight of air in a given volume. The

* This subject is dealt with in "Aeronautical Prints and Drawings," by Lieut.-Col. W. Lockwood Marsh, 1924, which contains many reproductions and an expert commentary thereon.

realization of this fact convinced the Académie that hydrogen—which according to Cavendish was but one-fourteenth of the weight of air—would provide a much more satisfactory lifting agent. It was thus the invention of the Montgolfière which stimulated the development of the hydrogen balloon, and it was largely to the credit of the Academie des Sciences that this was rapidly effected. Under its auspices the geologist Faujas de Saint-Fond raised a public subscription for the purposes of research and obtained the co-operation of the distinguished physicist J. A. C. Charles (1746–1823), to whom was entrusted the problem of generating sufficient hydrogen for the experiments, which involved production of the gas on a scale never previously attempted.

The manufacture of the first hydrogen balloon, which was an experimental model, was entrusted to the brothers Robert, mechanics who professed to have devised a method of impregnating silk with rubber in order to make it impervious to gas. Success depended naturally on the containing fabric being gas-tight, and they justified their contention by producing a bag of lutestring, treated with rubber, which proved to be adequately gas-tight. The bag was spherical, of approximately 13 ft. in diameter, and it was provided with an aperture and stopcock at the bottom designed to permit of its inflation with hydrogen. It was completed on August 23, 1783, and handed over to Charles for filling in readiness for the demonstration ascent, which was fixed for August 27.

The difficulties of producing sufficient hydrogen to fill the balloon were at once apparent. Charles devised a series of leaden chambers arranged one above the other; iron filings were placed in these compartments and dilute sulphuric acid was introduced from above. It appears that hydrogen was generated satisfactorily, but that a proportion of the gas leaked away—in fact, to such an extent that 6 hours of production resulted in practically nothing for the balloon. It must be borne in mind that, at this time, the method of collecting the gas over water had not been developed, though very shortly afterwards Charles employed it. The following day it was found necessary to empty the balloon as, during the night, air had entered through the stopcock, which a workman had left open. On August 25 it was, however, possible to produce with another generator almost sufficient hydrogen for an ascent. The inflation took place in the Place des Victories in Paris and, in the early morning of August 27, the balloon was conveyed in a cart accompanied by guards carrying torches to the Champ de Mars, where the demonstration was advertised to take place.

The first ascent was made at 5 o'clock in the evening; on the firing of a cannon the balloon rose majestically to a height of about 3,000 ft. and was soon lost to sight in low-lying clouds. It descended some time later in the village of Gonesse, 15 miles distant from the point of ascent, whereupon, it is said, it struck terror into the hearts of the peasant inhabitants of that village. Turnor in his picturesque account* states that the motion from the escape of gas, still contained in the bag, and the " awful stench " deterred a small crowd from approaching until one bolder than the rest stalked up and discharged his gun into the collapsing bag, upon which it was attacked with flails and pitchforks and finally tied to a horse's tail and borne across the country, torn to shreds.† Another account states that this " terrible apparition " was sprinkled with holy water in order to render it innocuous. Whatever may

* H. Turnor. "Astra Castra," London, 1865.

† An amusing engraving exists depicting this scene.

actually have occurred, it is clear that the appearance of a balloon was thought to be a supernatural phenomenon, so little was the new invention understood. It was even considered necessary by the Government of France to issue in 1783 an official warning to the effect that such machines were harmless. From the scientific standpoint the demonstration was a complete success, but it was not until November of the same year (1783) that the construction of the first man-carrying hydrogen balloon (Charlière) was undertaken by the brothers Robert under the supervision of Charles—the first human ascent having in the meantime been accomplished, as already described, in a hot-air balloon.

The hydrogen balloon designed by Charles was spherical and 26 ft. in diameter; it contained all the features essential to a free lighter-than-air aircraft of this type, namely, a car suspended from a network which enclosed the bag, a barometer, provision for taking ballast, and even a valve at the top of the bag to permit of the release of an excess of hydrogen. The provision of this valve was a remarkable proof of the sagacity of Charles in that he realized the necessity for reducing the pressure of the hydrogen in the balloon, when, as the external atmospheric pressure decreased with altitude, the internal pressure might increase to such an extent as to cause bursting. The balloon was composed of alternate sections of red and yellow cloth and the " gondola " was richly decorated in gilt on a blue ground. On December 1, 1783, Charles, accompanied by the elder of the brothers Robert, ascended from the Tulieries Gardens, and after remaining in the air nearly 2 hours, descended without untoward incident at the town of Nesle some 27 miles distant from Paris—a longer aerial journey than that previously accomplished by de Rozier. Charles then re-ascended alone—the descent having been necessitated by a reduction in the buoyancy—and rose rapidly to a height of over 9,000 ft., the experience being so alarming that it is said, on this account, he was deterred from ever making another ascent (see Plate VI).

It appears that on these ascents Charles was able to confirm, by means of the barometer which he carried, his prediction regarding the decrease in atmospheric pressure, and also to determine the decrease in temperature from a thermometer mounted in the balloon. Beyond this no new information was, it seems, obtained, but the ascents provided ample proof of the efficacy of the hydrogen balloon as a form of aircraft.

The period immediately following the development and first ascent of the hydrogen balloon, *i.e.* the year 1784, was remarkable for the amount of experimental work undertaken with the two rival types—the Montgolfières and the Charlières. Many successful ascents were made—ascents so numerous that mention of any save the more notable is impossible here—and the limitations, of the hot-air balloon in particular, were quickly realized. The outstanding disabilities of the free balloon, of either type, were found to be the total lack of any means of control for direction in the horizontal plane against the force of adverse winds, and only a limited control in the vertical plane for the purpose of ascent or descent. However, in spite of these disabilities the free balloon became immediately a popular demonstration in England, throughout Europe, and later in America. It was a comparatively safe adventure, and Cavallo remarks, in 1785, that over forty different persons had then made ascents and without loss of life, testifying to the " safety, ease and beauty of the experiment." Later it was recorded that of the first 1,000 balloon ascents only eight ended fatally.

The experimental work referred to above was concerned primarily with the development of a means of propulsion—so that the free balloon might be directed and be, at least to some extent, independent of the wind and able to follow a given course in fair weather. The question of propulsion was obviously of paramount importance—the gretaest problem to be solved if the balloon was to become a safe and practical vehicle of the air. The fallacy of the proposal to use sails was soon apparent. The use of animal power in the form of trained eagles, kites, and other birds was considered and abandoned by the more serious-minded. The possibility of propulsion by the reaction resulting from the emission of a jet of air or steam was considered and also the use of the explosive reaction of gunpowder fired in the form of a rocket. In 1784 the Frenchman Jean Pierre François Blanchard (1753–1809) first attempted to navigate a balloon against the wind by means of movable wings and a rudder. This apparatus was, however, soon discarded and he experimented with manually operated oars consisting of light framework covered with silk. It does not appear that these experiments were really successful, though Blanchard persisted in the use of oars and claimed that he was able to direct his balloon to a certain extent. Subsequently he was the first to employ a *moulinet*, or rotating fan, a device of some significance as one of the earliest applications of the principle of the screw for aerial propulsion.

At this period the assumed analogy between navigation on water and in the air led to the application of oars or similar devices and many such were tried, Etienne Montgolfier being among those who investigated the matter. It may be said that no attempt at propulsion by these means was really successful, or that adequate directional control of a spherical balloon was achieved. An attempt made during the same year (1784) by two Frenchmen, Miolan and Janinet, to propel a Montgolfière by means of the reaction resulting from the emission of jets of hot air from the balloon was, not unexpectedly, a complete failure. Propulsion, and so directional control, depended, as will be seen later, on the development of the airscrew and its application with a suitable prime mover to the adapted balloon. The alteration of the balloon to a shape suitable for navigation and its development into the dirigible was the next stage.

One of the most remarkable of the early aerial voyages was the first crossing of the Channel by Blanchard, accompanied by Dr. John Jeffries, a physician of Boston, U.S.A., on January 7, 1785. The undertaking was financed largely by Jeffries, and the ascent was made from Dover shortly after noon in a light favourable wind, the descent taking place in the forest of Guînes, not far from Calais. During the voyage, owing to some leakage, it was found necessary to discharge all the ballast—in fact, the aeronauts were ultimately obliged to throw out everything carried in the car, and even dispense with their clothes. The balloon used on this occasion was 27 ft. in diameter with a boat-shaped gallery suspended beneath in the manner devised by Charles. A compass and barometer were carried, also the "wings or oars" favoured by Blanchard, and other paraphernalia. Dr. Jeffries had previously, on November 30, 1784, ascended with Blanchard to determine facts concerning the state and temperature of the atmosphere at various altitudes, etc., and he may be credited with having made the first observations of a scientific character from a balloon.* The crossing of the Channel marked a stage in the progress of travel by air in that it was the first occasion on which two men were carried

* "Narrative of Two Aerial Voyages," 1786, by J. Jeffries.

through the air and over water from one country to another. Though the vehicle was quite unpractical from the standpoint of regular transport, the psychological effect of the achievement was considerable and analogous to that created in 1909 when the journey was made for the first time in an aeroplane by Louis Bleriot.

Blanchard, subsequent to the first crossing of the Channel, opened what was ambitiously described as a "Balloon and Parachute Aerostatic Academy" at Vauxhall, and during May 1785 made two notable ascents from London. He took with him on one occasion a passenger, Mlle Simonet, who thus earned the distinction of being the first woman to ascend in England. On June 3 he arranged the first parachute experiment made in England when he liberated a cat, which descended successfully—a demonstration of some interest in view of subsequent development. Blanchard, whose fame as a balloonist was probably unique, later made notable ascents in different parts of Europe, and on January 9, 1793, the first in America. He acquired, it is said, considerable skill in the management of balloons, but having little technical knowledge made no signal contribution to the scientific development of lighter-than-air aircraft his *métier* being that of professional aeronaut and showman.

After the first Channel crossing by Blanchard and Jeffries, the pioneer aeronaut Pilâtre de Rozier attempted to repeat the performance from France to England in a craft of unique design which apart from the tragic conclusion, deserves special mention. The balloon (Rozière) was a combination of Charlière and Montgolfière, in that while a hydrogen balloon supplied the main buoyancy, a hot-air balloon, situated beneath, was intended to add to the total lift and provide a means of regulating the ascent or descent which would be economical in gas and ballast. The theory of such a combination was sound, but the great danger due to the explosiveness of a mixture of hydrogen and oxygen when exposed to a flame was not apparently realized. De Rozier and M. Romaine, the maker of the balloon, ascended from Boulogne on June 15, 1785, but after travelling a short distance, a spark from the hot-air balloon reached the hydrogen bag, causing a violent explosion, and the two aeronauts were killed when the car fell on the rocks below. This was the first aerial fatality and, it is said, did much to damp the enthusiasm for the new science of aerostation.

As already remarked, the years 1784 and 1785 were notable for the number of successful ascents accomplished, many of which are historic. It is beyond the scope of this book to describe all those which may now be regarded as historic, but it should be recorded that the first ascent in Great Britain—a very brief one—was made at Edinburgh on August 27, 1784, by James Tytler (1747–1804), in a hot-air balloon, and the first ascent in a hydrogen balloon on September 15, 1784 by Vincenzo (known as Vincent) Lunardi (1759–1806), a secretary to the Neapolitan Embassy in London.* The latter ascent took place from the Artillery Grounds, Moorfields, London, in a balloon of approximately 33 ft. in diameter which was not, apparently, fitted with any valve—the aperture at the neck providing the only means of reducing an excess of pressure in the bag. Lunardi was accompanied by a dog, a cat and a pigeon on this occasion, and he carried oars to experiment, it is said, in directional control. The ascent was attended by H.R.H. the Prince of Wales and a distinguished company, and

* Actually, the first aerostatic experiment in this country was made by Count Zambeccari on November 4, 1783, when he launched a small hot-air balloon in London.

was made in view of some 150,000 people. The balloon, after an intermediate descent, finally landed near Ware in Hertfordshire, having drifted a distance of some 24 miles in about 2¼ hours. Lunardi published his account of the voyage * and subsequently the balloon and its appendages—including the cat and dog—were exhibited at the Pantheon in Oxford Street; on the whole he appears to have profitted considerably by his enterprise and during the next two years he further enhanced his reputation as an aeronaut by making many successful ascents (see Plate VII).

To James Sadler of Oxford (1751–1828) belongs the honour of being the first English aeronaut—the first Englishman to engage in ballooning with enthusiasm and success.† Sadler, who was brought up in the confectionery trade, appears to have begun experimental work on February 9, 1784, when he launched a demonstration Montgolfière balloon at Oxford with the "approbation of the whole University." He experimented with both hot-air and hydrogen balloons and constructed a large Montgolfière stated to have a capacity of 38,792 cu. ft. It was with this balloon that, according to the weight of the evidence, Sadler made his first ascent (from Oxford) on October 4, 1784, and thus achieved the distinction of being the first Englishman to ascend in England, Dr. Sheldon's ascent with Blanchard from Little Chelsea taking place fourteen days later. All the subsequent ascents made by Sadler were accomplished in hydrogen balloons. He contemplated crossing the English Channel, but abandoned the project when news of the successful crossing by Blanchard and Jeffries on January 7, 1785, reached him. In all, he made seven notable ascents—reaching a height of 13,000 ft. on one occasion—prior to forsaking aeronautics for nearly twenty-five years, during which period he was engaged in attempts to improve the steam engine and other matters. In 1810 he ascended again from Oxford and in 1812, after other ascents, crossed the Irish Sea from Dublin to Holyhead—a voyage which, however, ended in disaster, as the balloon was driven back by contrary winds and was forced to descend some 40 miles from the coast. James Sadler's two sons joined their father as professional aeronauts, but it cannot be said that any member of the family made a more notable contribution to the development of lighter-than-air aircraft. Sadler earned, however, distinction as a practical aeronaut and did much to demonstrate the balloon in this country.

The first successful human descent from a balloon by parachute was made by André Jacques Garnerin (1770–1825) at Paris in 1797, and a similar demonstration was given in London during September, 1802 with a parachute stated to be 23 ft. in diameter, the aeronaut being suspended in a basket beneath.

Thus closes a period, briefly but adequately described, which may be regarded as the first great period of achievement in that man was, at last, able to raise himself in the air. The achievement was strictly limited and by no means signified freedom to travel in that element, because the craft was subject to it rather than to the will of the passenger. Moreover, the very principle under which it functioned has restrictions in application by reason of the fact that a lighter-than-air aircraft must have considerable bulk, and as such must

* "An Account of the First Aerial Voyage in England," Vincent Lunardi, London, 1784.

† "The History of Aeronautics in Great Britain," J. E. Hodgson, 1924, contains a unique account of the work of James Sadler and his sons.

always be more influenced by, if not wholly subject to, weather conditions, and is not the free instrument which we would desire.

The Balloon during the Nineteenth Century

The practical art of balloon operation and of navigation was undoubtedly furthered in England by Charles Green (1785–1870). He introduced coal-gas as a lifting medium, as a result, it is said, of certain experiments he made in its production for lighting purposes. He observed that the gas obtained in the later stages of distillation, though considerably heavier than hydrogen, was sufficiently light to serve as a lifting agent in a practical balloon. The advantages were that coal-gas (which had been used for the street lighting of London since 1807) was comparatively economical and far more readily obtained, the production of hydrogen being then a slow and expensive process and its subsequent diffusion rapid. Green demonstrated the use of coal-gas before the Gas-Light Company in London in 1821, and later was frequently provided with gas free of charge for his ascents. He also developed the device then known as the "guide-rope," which was invaluable for navigation at altitudes up to about 1,000 ft. in that it reduced the necessity for alternatively discarding gas or ballast in order to maintain an even height. The rope was suspended from the car of the balloon, and when the height decreased it would trail on the ground and thus relieve the balloon of a fraction of its load, causing the balloon to adjust itself to a more or less constant altitude. It served also to reduce somewhat the shock of landing and at night indicated the contour of the ground passed over.

The most remarkable aerial voyage accomplished by Green was probably that commenced on November 7, 1836, when he ascended from the Vauxhall Gardens, London, in the balloon "Vauxhall" (subsequently renamed "The Great Balloon of Nassau") accompanied by Robert Hollond, M.P., and Thomas Monck Mason. It was intended by Green to test the balloon and guide-rope over land and water; in addition, the balloon was equipped with provisions, instruments, parachutes and 1,000 lb. of ballast with a view to a sustained voyage, the elaborate equipment being estimated, it was said, as sufficient for three weeks. The pear-shaped balloon had a diameter of approximately 50 ft. and a capacity of 70,000 cu. ft., giving a useful lift of some 3,920 lb. A west wind caused it to pass over the Channel at Dover, and over France the guide-rope proved of considerable value in maintaining a reasonable altitude. Green and his companions finally landed in the Duchy of Nassau near Weilburg, some 18 hours after the ascent from London, the balloon having travelled about 500 miles. This was the outstanding achievement of Green's career as an aeronaut, but he made numerous spectacular ascents in the "Nassau Balloon," which in different hands was in service for over thirty-five years.

Another famous British aeronaut was Henry Tracy Coxwell (1819–1900), whose ascents with James Glaisher (1809–1903), the first Honorary Treasurer of the Aeronautical Society of Great Britain during 1862–1865, were of importance as being undertaken for the purpose of scientific research. Observations were made in regard to the constitution of the atmosphere at high altitudes and experiments to determine its ability to support natural (heavier-than-air) flight were made. It is recorded also that they attempted

to take photographs (in the form of the daguerreotype) from the air, but owing to the evolutions of the balloon, without any marked success. Coxwell subsequently acquired the "Nassau Balloon," and, after reconstructing it, attained an altitude of 10,000 ft. on one occasion.

Before passing to the consideration of the technical features of the modern spherical balloon, its uses and operation, it is of interest to note briefly the facts of its early popularity and decline. It will have been appreciated that at first the balloon was a vessel of doubtful utility, its applications for the purposes of scientific research were immediately realized, but at that time the equipment of physical science had not reached that stage of development whereby the balloon could be used to full advantage. In default of any satisfactory means for propulsion the balloon was not a practical vessel and its *métier*, during the early years of its development, was mainly that of providing enterprising showmen with substantial profits.* The potentiality of the captive balloon as a means of reconnaissance in war was, however, immediately apparent, and we find that as early as 1794 it was used with success by the French in the Battle of Fleurus and, subsequently, during the siege of Mayence. It is interesting to note in this connexion that between the years 1790 and 1800 only six ascents were recorded in France, the lack of activity being due in part, it is said, to the fatal accident to Pilâtre de Rozier in 1785, and also to the upheaval of the French Revolution. During the siege of Paris in 1870 a mail and passenger service was organized by Felix Tournachon (Felix Nader), and appears to have been the earliest successful venture of this kind. Between September 23, 1870, and January 28, 1871, 164 persons, some animals and a large quantity of mails were safely transported in balloons from the city. To a Frenchman, the aeronaut Arban, belongs the credit of having made the first aerial crossing of the Alps in 1846, while an historical attempt to explore the polar regions in a balloon was made by Salomon Auguste Andrée in 1897—an expedition which ended in tragedy. In England experiments were made at Woolwich Arsenal in 1878, and balloons took part in the military reviews and manœuvres of the period. By 1890 the balloon operations of the detachment of the British Army were considered so successful that a regular balloon section was formed as a unit of the Royal Engineers, and an official factory was established a little later at Chatham.

Fantastic and ludicrous designs for free balloons were advanced from various quarters, probably the most ambitious being that proposed in all seriousness by E. G. Robertson from Vienna in 1804. The proposed balloon, "La Minerve," was intended to accommodate some sixty persons, in addition to numerous appendages, with a view to an aerial voyage of several months' duration for the purpose of scientific observation. The description of this project, reprinted in Paris in 1820, serves as evidence of the complete failure to appreciate the most obvious limitations of the free balloon—a failure which was prevalent in many quarters at the beginning of the nineteenth century.

The Modern Balloon

It is desirable to include at this stage some notes on the modern use of the balloon rather than to return to the subject later. The modern spherical

* From about 1830 to 1850 balloon ascents were very frequent, and considerable sums were paid by passengers desiring to make an aerial voyage.

balloon differs little in essentials from the earliest Charlière. The gasbag, roughly spherical in shape and made of rubbered fabric, has a tubular extension known as the neck, and after inflation it is always left open as a safety precaution; any increase in internal pressure due to expansion of the gas is usually relieved by means of a valve operated by the aeronaut. The balloon is not fully inflated at the time of ascent, so that on rising the expansion of the hydrogen will completely fill the gasbag. The car, or basket, is suspended beneath the gasbag by a network of ropes passing over it. Two controls are available, the valve for releasing the gas, and the ballast, usually in the form of water or sand, which can be dropped to lighten the balloon; in practice both gas and ballast are conserved as long as possible. The alternative method of control by a trailing rope has already been described; such a method has obvious disadvantages. In addition to the trailing rope, another device known as the "deviator," for use when travelling over water, has been employed, and numerous types of water anchors and grapnels have been developed for balloon use. Also, a device known as the "ripping panel," introduced by the American aeronaut John Wise in 1844, has been used in order to empty the gasbag rapidly on landing and reduce the danger of bumping along the ground.

A knowledge of the weather conditions prevailing and the strength of the wind at various altitudes, obtained from meteorological reports or from a knowledge of local conditions, is essential to the successful operation of a free balloon. While in the air a gradual leakage of gas from the balloon may occur from various causes; radiation from the sun will expand the gas and cause some to escape, while the presence of clouds may reduce its temperature. Such changes in temperature lead gradually to a decrease in the amount of the hydrogen in the balloon and a consequent reduction in the buoyancy; for this reason the experienced aeronaut employs his ballast as little as possible, because when all is used up effective control ceases. An instrument known as the statoscope, which is highly sensitive to changes in atmospheric pressure and so records the rate of ascent or descent, is invariably carried.

To-day the spherical balloon is used almost exclusively for sporting purposes. The inauguration of the Gordon-Bennett international balloon races in 1906 stimulated the art of ballooning, and this contest is still held annually, the object being to travel the longest distance as measured from the point of departure to the point of descent along a great circle of the earth. The contest is valuable as a training in aerostation; rapidity of travel is, in view of the factors already referred to, of great importance. There is, however, another and very important purpose for which the balloon has been used during recent years; that is, for meteorological research in the region known as the stratosphere. Small balloons employed for meteorological purposes and carrying only instruments have ascended to great altitudes, a height of over 20 miles having been recorded, but in recent research full-scale balloons carrying several persons have been employed. On May 27, 1931, Professor A. Piccard, of the University of Brussels, accompanied by M. Kipfer ascended from Augsburg, Bavaria, in an air-tight spherical cabin, raised by a hydrogen-filled balloon, and reached a height of 9·5 miles. During a second ascent on August 18, 1932, a height of 10·5 miles was attained, the main objective in both cases being the investigation of cosmic radiations. On November 11, 1935, Capt. A. W. Stevens and Capt. O. A. Anderson of the United States

Air Corps reached a height of 74,000 ft. (over 14 miles) in a stratosphere balloon, thus establishing a world altitude record for aircraft.

Balloons when tethered to the ground by rope or cable are known as "captive" and "kite" balloons, and are generally used for observation purposes. It is interesting to note that a proposal to use balloons from ships was made as early as 1803 when Rear-Admiral Sir Charles Knowles wrote to the Admiralty suggesting their employment to observe enemy preparations in the harbour of Brest and in other ports, "without the expense of intelligence by spies," would be practicable.

The disadvantage of the spherical balloon under such conditions is that it may rotate about a vertical axis and render observations difficult. In 1896 the disadvantage of rotation was overcome by designing a balloon of an elongated form with a vertical lobe at the rear so that the nose kept head on to the wind and the tendency to drift was reduced. This type of balloon, the "Drachen," was constructed in Germany; the main gasbag was filled with hydrogen, but the lobe, or fin, contained air collected by a scoop facing towards the nose. As the wind increased, the lobe was distended by the air-pressure and acted as a vertical stabilizer in the manner of a weather-cock. In France, later developments of the kite balloon had three fins, which gave generally greater stability, but there remained a slight lateral instability.

Kite balloons were used extensively for observation during the 1914-18 war, both over land and water, and, during the same period, they were employed on a few occasions to carry a protective "apron" designed to aid in the defence of London against attack from the air. That method of defence involved the use of a number of kite balloons which lifted a horizontal cable from which many wires were suspended in order to foul the wings or structure of enemy aeroplanes and to cause thereby damage or loss of control. It was revived in 1937 when the London Balloon Barrage Group was formed as a part of the R.A.F. defences against aerial bombardment, and it was in use during the Munich crisis of 1938. The purpose of the modern balloon barrage is to prevent low-level attacks by hostile aircraft on densely populated areas or specially selected military targets such as ports, factories, naval bases, etc. Balloons were also operated from ships to guard convoys and were used in the defence of the Suez Canal. The efficacy of the balloon barrage was proved during the Second World War and it was used by all the belligerents, though its limitations in regard to operational height—determined by the weight of cable to be carried, and to other factors—were well recognized. It is recorded that the balloon barrage of Southern England brought down 278 flying bombs (V1.) during the latter part of 1944.

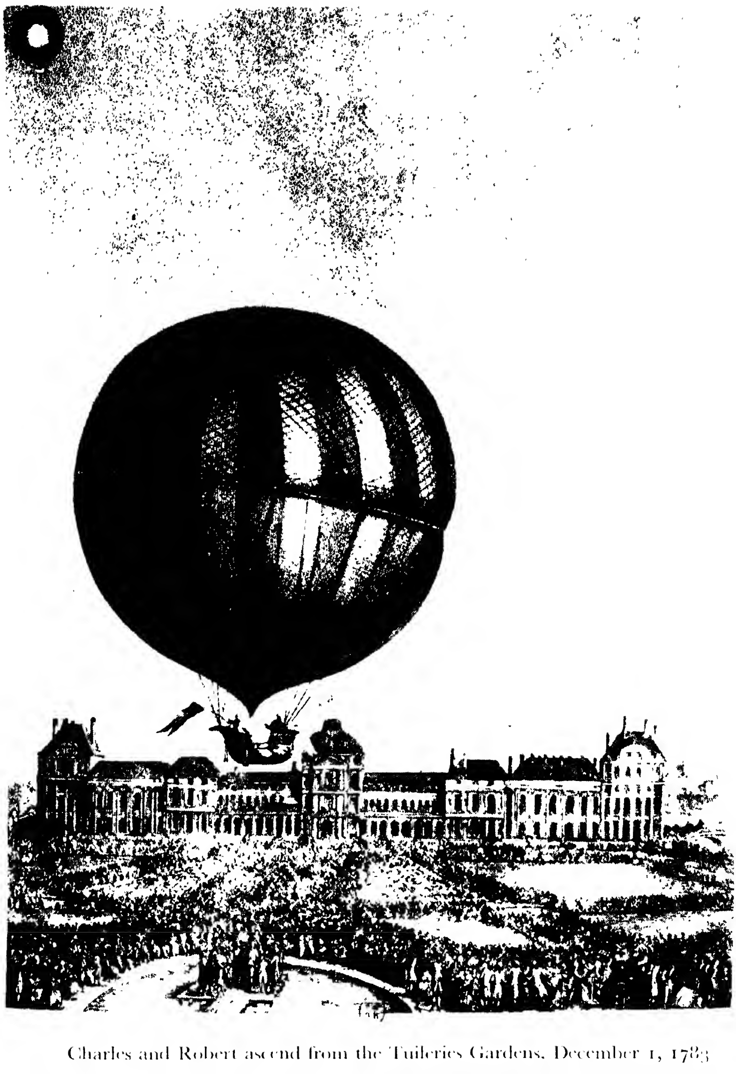
When observation balloons operate at any appreciable height—which may be only a few hundred feet—they are usually attended by a special tractor which carries a winch for releasing the long cable from a drum and for hauling down the balloon when required. Kite balloons are subject to the danger of ignition from electrical discharge during thunderstorms—the cable acting as a conductor; devices to ensure reasonable protection against fire have, however, been developed.

As already remarked, it is obvious that the free balloon, without any means for propulsion, is not a practical aircraft in the sense that it cannot be controlled and directed at will, and it is thus not an effective means of transport.

The resort to an elongated form to facilitate navigation, the introduction of control surfaces, and the application of the necessary driving power will be described in the next chapter, which deals with the development of the dirigible balloon or airship.

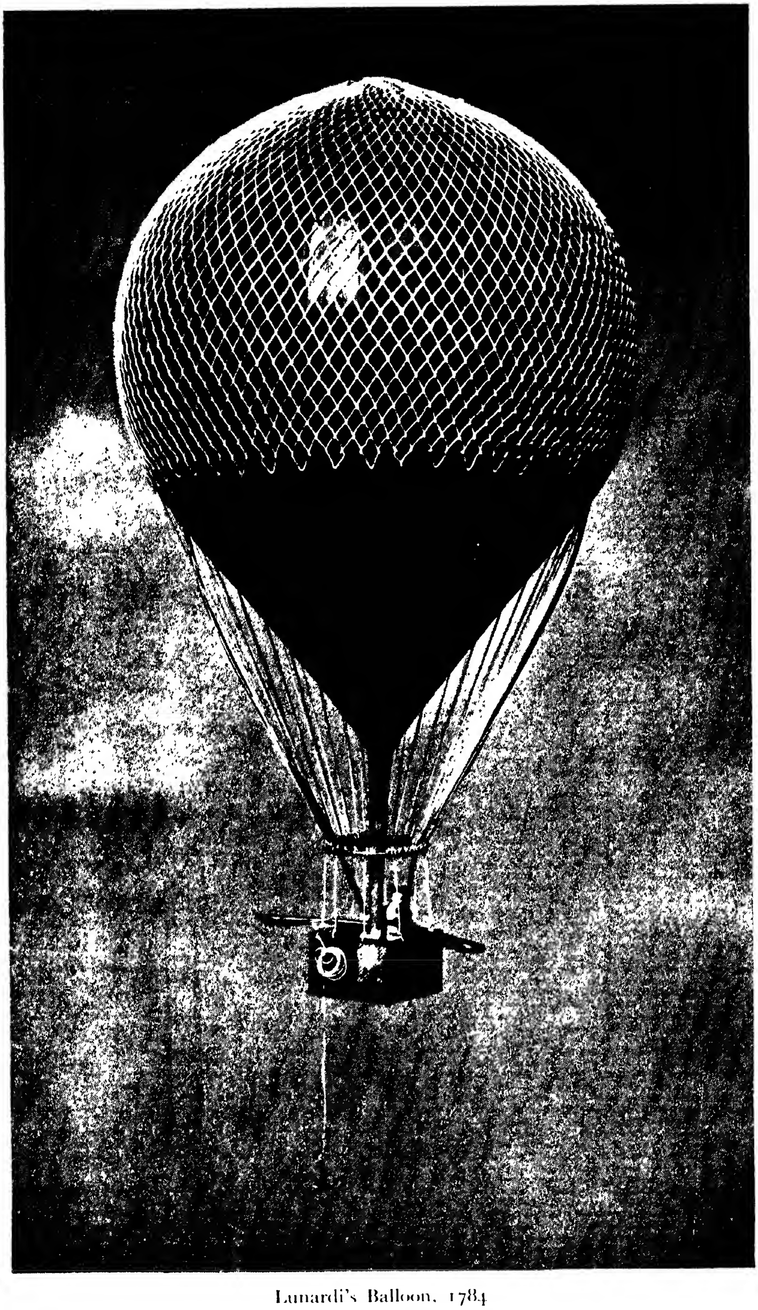
The balloon, as originally devised, may, however, have a future in its use for purely recreational purposes. The fascination of silent, effortless travel which it affords has been testified by those who practised the art in the past and by the few who to-day are aeronauts. There is, it is said, a singular relaxation to be found in ballooning, the surrender to natural conditions constituting in great measure its charm. However that may be—and the presence of high-tension cables and other obstructions in the modern countryside would make such abandonment more risky than it was—there should be scope for a revival of ballooning as a comparatively safe, cheap and healthy recreation.

PLATE VI



Charles and Robert ascend from the Tuileries Gardens, December 1, 1783

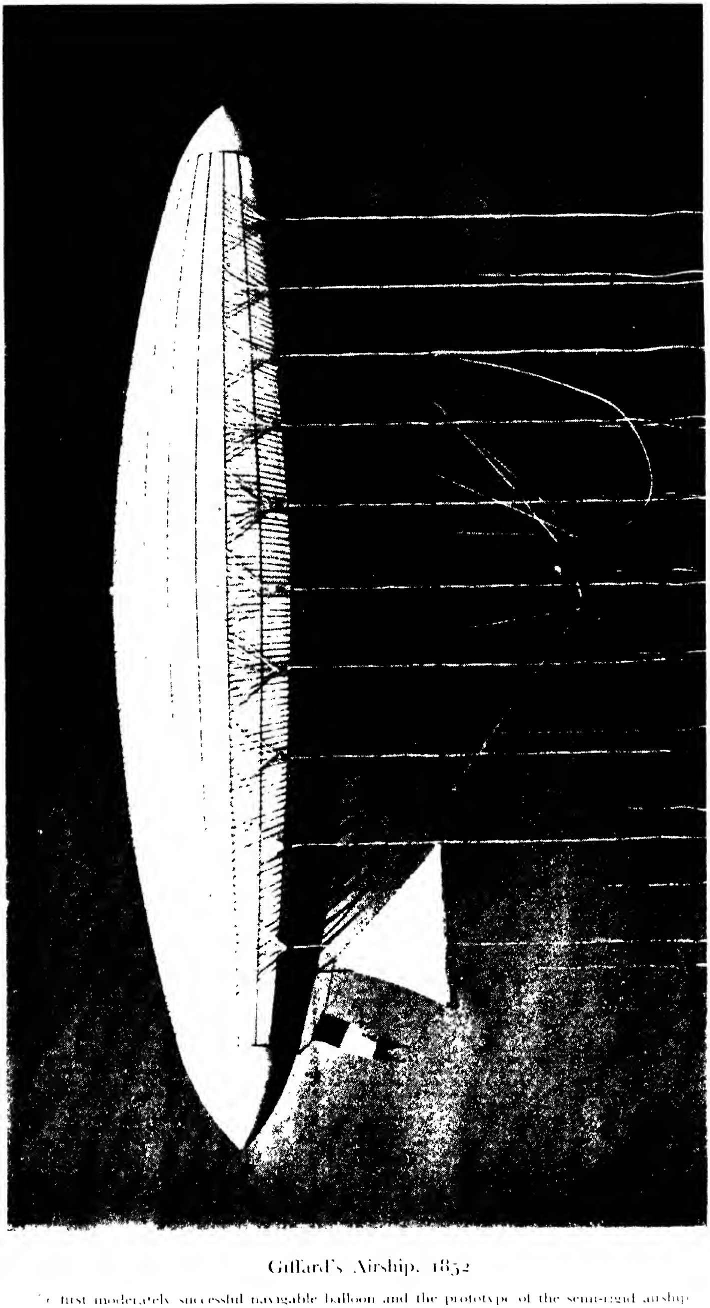
The first ascent in a hydrogen balloon was witnessed by many thousand people, a small ballo preceded it (See Page 32)



Lunardi's Balloon, 1784

The first hydrogen balloon ascent in England was made by Vincenzo Lunardi from Moorfields in London, September 15, 1784 (*See Page* 35)

PLATE VIII

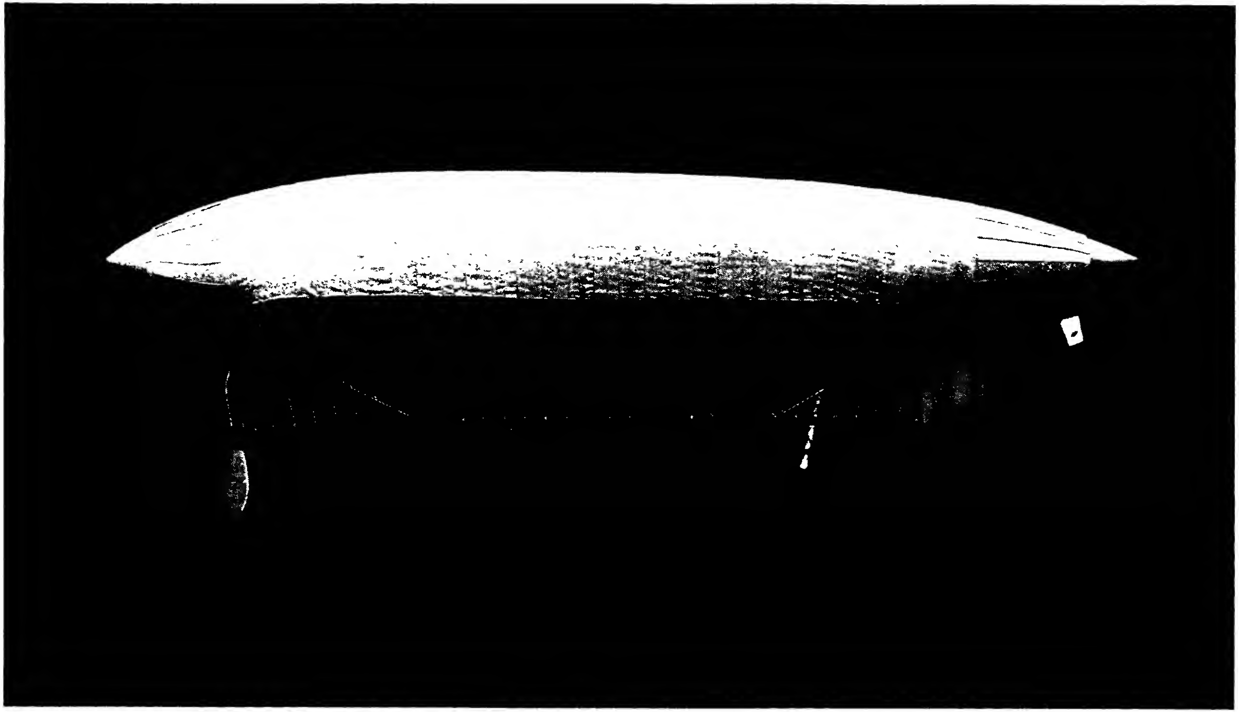


Giffard's Airship, 1852

The first moderately successful navigable balloon and the prototype of the semi-rigid airship

See Page 45

PLATE IX



The Airship "La France," 1884

Driven by electric power this dirigible balloon was capable of steady flight under control and was able to return to its starting point. See Page 47

VII. DEVELOPMENT OF THE DIRIGIBLE BALLOON OR AIRSHIP

1783–1919

IN ORDER TO DESCRIBE the development of practical lighter-than-air aircraft, it is necessary to return to the year 1783—the year of the invention of the balloon—because the first stage in the gradual evolution of the airship was reached almost immediately, though it was a hundred years before any real success was attained. It is thus a long period which must be traveresd before we reach the successful airship, and it is desirable to extend these notes to include the development up to the year 1919, which may be regarded, in the perspective of to-day, as the end of the historic epoch. This method has the obvious advantage of continuity in dealing with one aspect of flight, and it makes it unnecessary to interrupt the main narrative by returning frequently to the subject of airships; moreover it enables the reader, if he is not interested in the subject, to ignore it. Consideration of the airship from the standpoint of modern air transport comes appropriately in Chapters XII and XIII.

The first stage in development was the realization that in order to make a balloon navigable it should be elongated in shape rather than spherical, in accordance with the principles of navigating in water of which nature provided so many excellent examples. The outstanding figure in the early history was undoubtedly the French officer Jean Baptiste Marie Meusnier (1754–1793), who made, in 1783, the first profound contribution in regard to the directional control of a lighter-than-air vessel. Meusnier, who was a lieutenant in the Corps of Engineers and later a general in the French Army, presented to the Académie des Sciences on December 3, 1783, a memoir on aerostatic machines,* in which he first proposed the use of a ballonet which could be filled with air by a pump or emptied as required, his intention being, it has been said, to vary the weight of the balloon and so provide a means of controlling its altitude without the use of ballast. Whatever his original intention may have been, the full significance of this invention of the ballonet, as a means for preserving the shape of the balloon, was soon apparent. During the following year (1784) he produced a series of drawings† for the design of an ellipsoidal balloon 260 ft. long, the most salient feature of the design being the departure from the spherical form. He seems to have been the first to appreciate that the shape of a navigable balloon should be ellipsoidal rather than spherical—that it should accord in principles of navigating with a water-borne vessel, *i.e.* that it should have a definite bow and stern. He incorporated in the design his suggestion for pumping air into an outer envelope, which would serve to maintain a constant pressure in the balloon, and in addition he proposed the use of three airscrews (*rames tournantes*), to be operated by manual power—the first recorded design for the application of the screw in a practical form for the propulsion of aircraft. In this connexion it is of interest to note that, from the evidence available, it appears that the application of the airscrew to propel a vessel on water slightly antedated Meusnier's proposal, such an application

* "Mémoire sur l'équilibre des Machines Aérostatiques, etc.," Paris, 1784.

† These drawings are preserved in the Musée de l'Air, Paris.

having been made earlier in 1784.* This use of an airscrew, in the form of a wheel composed of blades set at an angle, is attributed to M. Vallet, director of a chemical factory at Javel, and it is said to have been employed to propel a boat on the Seine. In 1875 a spherical balloon constructed by M. Vallet, and known as "L'Aérostat de Javel," made several ascents while fitted with two "wheels" each having four blades, and it may be assumed that the previous use of the device on a boat was in the nature of a test to determine its suitability for propulsion in the air.

The design for Meusnier's airship included a triangular suspension system for the car in conjuction with girth fastening, *i.e.* the attachment of the suspension cords to girths surrounding the balloon. He also proposed a portable tent for protecting the airship and a permanent hangar for housing it. His conception of an ellipsoidal balloon unquestionably marks the inception of the airship and his plan for propulsion was far ahead of any hitherto proposed. The vessel was never constructed owing to the then prohibitive costs, but the fundamental features were incorporated in the first airships and his suggestion of the ballonet to prevent deformation of shape was later most successfully employed. France lost the inventive genius of General Meusnier in 1793, when, at the age of thirty-nine, he was killed in the fighting before Mayence. It is recorded that, on account of his unusual attainments, the King of Prussia ordered all firing from his army to cease until the interment had taken place.

An attempt to apply the principle of the ballonet was made almost immediately by the brothers Robert, who were also the first actually to construct an elongated balloon. The balloon, ellipsoidal in form, was made by the direction of Louis Philippe, Duc de Chartres, who financed the construction; it was much smaller than that projected by Meusnier. On July 15, 1784, the brothers Robert accompanied by the Duc de Chartres ascended from St. Cloud, but the trial was far from successful and a serious accident, due to excessive gas pressure, was narrowly averted. It seems that no valve was fitted to allow for expansion, and the silk envelope became distended to the point of bursting when, it is said, the Duc de Chartres relieved the pressure by piercing the envelope with the spearhead of a flagstaff which was carried in the basket. The means for propulsion consisted of four or five "revolving oars," operated by the occupants of the balloon, and it has been stated that these produced a thrust of 140 lb. The propulsion proved quite inadequate, however, and this trial and a subsequent one contributed nothing to the problem of directional control; in fact, it has been suggested that the lack of success in these experiments definitely delayed progress by weakening confidence—quite unjustly—in Meusnier's proposals. There followed a period of nearly seventy years during which but little was achieved in regard to the development of the airship, but it will be appreciated that this was due mainly to the lack of a suitable prime mover. This lack of adequate propulsive power rendered all the early efforts unavailing, and was an insuperable obstacle to success. During that period (1784-1852) a number of designs for dirigible balloons were produced both in England and France, and in some cases they were actually constructed, but the experiments served only to establish the fact that elongated forms, moving in the direction of their greatest length, offer less resistance to the air than the spherical form. The experiments

* "Recherches sur l'Art de Voler," David Bourgeois, 1784.

served also to demonstrate the complete inadequacy of manual power to propel a balloon.

In 1789 Baron Scott, a French Dragoon officer, published a proposal* for a fish-shaped balloon which included two-air pockets, or ballonets, one in front and one in the rear, to be inflated or deflated in order to increase or diminish the buoyancy at the opposite end of the balloon and thus obtain an inclination for ascent or descent—a suggestion which was much later adopted. The proposal is said to have inspired John Pauly, a Swiss gunsmith and engineer, who in 1804 actually constructed a " fish-formed " balloon in Paris. In 1816 he began to build another, in collaboration with Durs Egg, at Knightsbridge, London, but it was never completed; the design included a movable weight to control and preserve the trim of the balloon—a device which was also adopted later. The cost of this venture was said to amount to £10,000. Sir George Cayley (1773–1857), whose principal work is described later in this book, also published† proposals for navigable balloons, and though his contributions to the subject of lighter-than-air flight were less profound than those in the field of mechanical flight, they provided a much needed exposition of the principles underlying the airship. In this connexion he pointed out that the surface of a balloon increases as the square of its diameter (and hence its resistance to forward motion) whereas the volume of the buoyant gas it may contain increases as the cube of the diameter—the larger the vessel, the larger in even greater proportion its capacity for useful load. Thus Cayley advocated large navigable balloons and he proposed to substitute " acres for yards of cloth " in their construction. It is apparent that, without overlooking the great expense involved—at that time it was well-nigh impossible to obtain funds for balloon projects on a large scale—or the difficulties attendant upon handling and storing a large navigable balloon, Cayley was too sanguine in regard to the structural problems involved, which, according to recent experience with large rigid airships, are formidable. His considered opinion that " on a great scale balloon floatage offers the most ready, efficient, and safe means of aerial navigation " may not be generally accepted to-day, but it was formed before his own investigations in the subject of mechanical flight were completed, and at a time when there was no certain conviction that an engine suitable for propulsion of a heavier-than-air machine would ever be available.

Cayley considered the use of the steam engine in default of any more suitable engine and also the many other factors involved in the construction of a dirigible balloon. His contentions were supported by calculations which, if not in all cases accurate, were an important advance on any previously advanced, at least in England. It must be borne in mind that the limited scientific knowledge of the day, and the almost total lack of data from experimental work, made it necessary for every investigator to approach the subject as from the beginning. There is little doubt that his conclusions were based on some actual experiments, and it is because he endeavoured in a scientific manner to obtain reliable data and to make the knowledge available, that he ranks as a pioneer in the strictly scientific development of the airship. His ability in mechanical science was coupled with a singular imaginative foresight. His vision carried him beyond technical development. He wrote: " The

* " Aérostat dirigeable a volonté," Paris, 1789.

† Tillock's *Philosophical Magazine*, Vols. XLVII and L, 1816-1817. Also *Mechanics Magazine*, Vol. XXVI, 1837.

subject . . . is one of great interest, not merely in a mechanical point of view, but as to its stupendous effects on mankind at large; civilization and, I trust, perpetual peace are in its train of consequences." The apprehension of Francesco de Lana was again expressed.

In contrast to the scientific attitude of Sir George Cayley, a contemporary airship, Lennox's "Eagle," showed that the application of the airscrew as essential to successful propulsion was not realized. "L'Aigle," which was described as "the first Aerial Ship," was constructed in France in 1834 on the initiative of Count Lennox, who has been described as a French colonel of infantry of Scottish descent. On August 17, 1834, an ascent was attempted from the Champ de Mars, but owing, it is said, to faulty workmanship, the netting broke, the inflated gasbag escaped and burst, and the remainder of the machine was destroyed by the crowd. A second airship was generally similar, but was constructed in London "for establishing a direct communication between the capitals of Europe," the initial service to be between London and Paris—a project characteristically ambitious—and was exhibited in June 1835, at Kensington and later at Vauxhall Gardens, when an ascent was promised but never took place. The means for propulsion consisted of eight paddle-shaped flaps, four on either side of the balloon, which were to be worked fore-and-aft by manual power through the medium of cords and chains. It appears that Count Lennox had little faith in his design and that the receipt of gate-money was the only benefit derived from his enterprise. The means of propulsion—though never tested—was obviously impracticable, and the "Eagle" serves only as a record of ineptitude.

In 1838 Thomas Monck Mason, an operatic manager and at one time lessee of His Majesty's Theatre, published in London a large volume entitled "Aeronautica," which contained an account of his observations while a passenger in the famous "Vauxhall Balloon" on her voyage to Weilburg, and a statement of the main principles involved in the use of balloons and notes on their propulsion and control. He also constructed a working model of an ellipsoidal balloon 13·5 ft. long, with a capacity of 320 cu. ft. and weighing 17 lb. It was fitted with an Archimedean screw actuated by clockwork and, when exhibited at the Adelaide Gallery in the Strand in 1843, it was successfully propelled by this means at a speed of about 4 miles an hour.

The success of Monck Mason's dirigible served possibly as an inspiration to the French clockmaker Pierre Jullien, who undertook experiments at the Hippodrome in Paris in 1850. His model was ambitiously named "Le Précurseur," but the design was unquestionably the work of a singularly gifted man, and it is known that it influenced Henri Giffard in his construction of the first successful airship two years later. "Le Précurseur" is stated to have had a good elongated form, probably representing an advance on any streamline shape previously employed; it was provided with both vertical and horizontal "rudders," a notable feature, and it was driven by clockwork through propellers placed on either side. Unfortunately the funds available were insufficient to allow Jullien to develop his machine and he abandoned the work in 1851. It seems probable that, under different circumstances, he might have met with success, though it would have depended on the provision of a suitable prime mover.

Full-scale experiments were made in England during 1850 by Hugh Bell, a member of the medical profession, who in 1848 had filed a patent

specification (No. 12,337) relating to a navigable balloon, and he constructed one called the "Locomotive Balloon," 50 ft. long and 22 ft. in diameter, with conical extremities. The gasbag, which was made of silk, had a capacity of 15,000 cu. ft., and when inflated with coal gas the machine was alleged to provide for a useful load of some 500 to 600 lb. It has been said that Bell was the first man in England to apply the screw propeller in actual full-scale experiment in the air, and on the occasion of the first trial, made from the Phœnix Gas Works at Kennington Oval during May 1850, an airscrew 6 ft. in diameter was employed. The ascent was successful, but the balloon merely drifted some 30 miles in about 1·5 hours.

The various projects and inventions already described represent only a small proportion of the many schemes which originated during the first half of the nineteenth century. Some were merely fantastic; a few, though rational, were, in the light of contemporary resources, impracticable. The problem of propulsion in the air, of directed navigation, remained unsolved—though nearly seventy years had elapsed since the invention of the balloon—because no suitable engine had been developed for the purpose, and it was owing to a fortunate train of circumstances that the application of mechanical power to lighter-than-air aircraft was not even further delayed.

The credit for the construction of the first truly navigable balloon belongs to the illustrious engineer Henri Giffard (1825–1882), who is perhaps best known as the inventor of the steam injector. The genius of Giffard, coupled with the wealth he acquired from that invention, enabled him to undertake experimental work and to concentrate upon the design and construction of a steam engine sufficiently light to permit of its installation in a balloon. In 1851, he began the construction of a light-weight steam engine of nominally 3 h.p. In a patent subsequently applied for, he described also a model dirigible balloon with screw propeller. In 1852 he constructed his first airship, elongated in form, symmetrical and with pointed ends; its length was 143 ft. and its greatest diameter 39 ft., with a capacity of 88,000 cu. ft., the lifting agent being coal gas. The steam engine, completed during the previous year, was stated to weigh with its boiler 350 lb. or approximately 117 lb. per h.p. It drove a propeller 11 ft. in diameter at 110 r.p.m. and was capable, according to the first calculations, of producing a speed of 6 m.p.h. In order to minimize the danger from fire which might result from the ignition of any escaping gas, Giffard suspended the car containing the engine 20 ft. below the gasbag, and he took a further precaution by screening the stokehole of the boiler with wire gauze—an application of the principle originated by Sir Humphry Davy in connexion with the miner's lamp (see Plate VIII).

On September 24, 1852, Giffard ascended from the Hippodrome in Paris—the scene of many other trials—and accomplished a quite successful flight. He landed safely near Trappes, a distance of some 17 miles, having travelled at a speed stated to be from 4 to 5·3 m.p.h.—the speed in still air being estimated as about 5·5 m.p.h. He was able to make some useful experiments with a triangular sail which served as a rudder, situated at the rear of the machine, and he was able thereby to deviate from the direction of the wind, but he was apparently unable to navigate in a circle or to return to the starting point, owing doubtless to an insufficiency of power.

Giffard's dirigible was notable not only as the first moderately successful navigable vessel, but also as the general prototype of the later semi-rigid type

of airship. His success with it was remarkable in view of the fact that it contained no ballonet to maintain the shape of the balloon under varying pressures, but as no very considerable altitude was reached the consequences of this deficiency were probably not much felt. In 1855 he constructed a second airship, which was slightly larger, and proposed a third airship of vast proportions. A brilliant record of achievement ended in tragedy when Giffard became blind and died prematurely in 1882; he had demonstrated at last the possibility of aerial navigation by means of a lighter-than-air machine furnished with an engine and airscrew.

Evidence that appropriate motive power was not yet forthcoming was further provided by the experiments of S. C. H. L. Dupuy de Lôme (1816–1885), who reverted to manual power in the construction of a dirigible balloon in 1872. It embodied a new form of triangular suspension for the car and an air ballonet with blower or air-compressor; these were important features not previously incorporated in actual construction—the application of the ballonet being intended for maintaining the gasbag fully distended regardless of leakage of gas or decreased atmospheric pressure. A four-bladed propeller was worked by eight men, and on the occasion of the only trial, which was made at Vincennes on February 2, 1872, it is stated that a speed of about 5 miles an hour was attained. The dirigible incorporated, in rudimentary form, the essential features of modern non-rigid design, including an envelope of two-ply rubberized fabric, and it showed that in airship design a stage had been reached whereby the onus of further progress rested mainly upon the engineer who could develop and apply the indispensable prime mover.

The distinction of being the first actually to employ an internal combustion engine for the propulsion of aircraft belongs to the German engineer Paul Haenlein (1835–1905), who in 1865 patented a design for an elongated navigable balloon provided with a horizontal framework beneath it designed to serve as a rigid keel. A primitive gas-engine of the Lenoir type drawing its fuel from the balloon, the shape of which was to be maintained by a ballonet and blower, was proposed. Haenlein completed the construction of his airship at Brunn in 1872; the four-cylinder Lenoir type engine drove two four-bladed propellers at about 40 r.p.m. and was stated to develop 5 h.p. The trials, made during December 1872, demonstrated a perceptible control and a narrow margin of independent acceleration, but the performance was apparently not such as to indicate any marked advance, though it was said a speed of 10 m.p.h. was attained, and the importance of the event lies mainly in the fact that it was the first application of an alternative and very significant form of power—the internal combustion engine.

In 1882 the application of yet another source of power was made by the brothers Albert (1839–1906) and Gaston (1843-1899) Tissandier, who constructed a dirigible, fitted with a Siemens electric motor of 1.5 h.p.—the current being obtained from twenty-four bichromate of potash cells stated to weigh approximately 500 lb. A trial was made at Auteuil on October 8, 1883, when, in spite of a slight wind, some control was effected and a certain deviation was obtained by the use of a rudder in the form of a sail. A second trial on September 26, 1884, produced somewhat better results, but the low power available was naturally ineffective in a wind of any appreciable velocity

and the experiments were abandoned after the brothers had expended a considerable sum of money.*

An event of outstanding interest in the history of aerostation immediately followed the earlier experiments of the Tissandier brothers. In 1884 Charles Renard (1847–1905), an engineer of distinction and at one time director of the French military balloon establishment at Chalais-Meudon, near Paris, and a French officer, Captain A. C. Krebs, designed and constructed a dirigible named "La France" which was capable of steady flight under control and able to return to the point of ascent. The airship "La France" was 165 ft. in length and of about 27 ft. in diameter at the largest part, which was forward of the centre, the form being remarkably good and approximating to modern streamline shape. The envelope, which had a capacity of 66,000 cu. ft., was made of varnished Chinese silk and was built up of longitudinal gores converging towards two points. The suspension of the car was effected by parallel cords from rigging bands enveloping the balloon (a network had been abandoned) and the car, which was about 108 ft. long, was constructed of bamboo. A large vertical rudder and a smaller horizontal elevator plane in addition to a sliding weight, provided for control. The power unit consisted of a Gramme electric motor developing 8·5 to 9 h.p.—a marked increase on any power previously employed—and it weighed about 210 lb. The current to drive it was obtained from chromium chloride batteries, invented by Renard, which were (for that period) extremely light in weight. The motor drove a large tractor airscrew and the total weight of the airship was stated to be 4,000 lb.

The first trial of "La France" was made from Chalais-Meudon on August 9, 1884, and proved adequately successful. Renard and Krebs ascended safely and having completed a circular flight of a little less than 5 miles in 23 min., which represented a speed of from 12·5 to 13 m.p.h., landed at the point of departure. Six other flights were made during 1884–1885, and on four occasions the initial success was repeated; the two final flights were made over Paris, and it is said that they served to convince the French authorities that the dirigible balloon was at last a practical possibility. At the same time it was apparent that the considerable weight of the motor and batteries for the relatively low power, indicated that electric propulsion did not provide a final solution, and was, moreover, restricted in use to comparatively short distances with no load beyond the bare necessity of an operating crew. For these reasons no spectacular development immediately followed the triumph of Renard and Krebs (see Plate IX).

In Germany an event of some significance was the construction by the engineer David Schwarz of a metal-clad airship which was tested at Berlin in 1897. Schwarz had in 1893 designed a previous vessel which was not successful, but his second airship is of outstanding historical interest on account of the material used in its construction, and the fact that it was the first wholly rigid design. The airship was cylindrical in form, with a conical nose and rounded stern, and was built up on an inner lattice framework of aluminium tubing, the envelope being constructed of aluminium sheet stated to be 0·008 in. in thickness. The filling of the metal envelope was accomplished by the introduction of a number of bags inflated with hydrogen, by means of which

* Tissandier, G. "Histoire des ballons et des aéronautes célèbres," Vol. II, Paris, 1887-1890.

the air contained in the envelope was expelled—a necessary proceeding which in the case of a fabric bag was accomplished by merely collapsing it. Another notable feature of the airship was the application of a gasoline motor in the form of a primitive two-cylinder engine by Daimler. The trial, which as already noted took place in 1897, was a failure owing to leakage of gas and faulty transmission of the power to the airscrew. A soldier named Platz, who made the ascent, narrowly escaped when the car struck the ground after a rapid descent, and the airship was subsequently destroyed without any success in its navigation.

Actually, the first application of an internal combustion engine consuming liquid fuel was made by two German engineers, Wolfert and Baumgarten, the type of motor used being one of the earliest evolved by Daimler from which the successful internal combustion engine for car propulsion was developed.* Unfortunately the experiments did not supply any very useful information as the dirigible, being faulty in construction, was wrecked almost immediately on launching. During the final test on June 12, 1897, at Berlin, an explosion occurred, causing the death of Dr. Wolfert and his assistant, Knabe.

The modern development of the non-rigid type of airship may be said to date from the early experiments of the Brazilian inventor Alberto Santos-Dumont (1873–1932), because they constitute the close of the historic period of endeavour prior to the establishment of the airship as a practical vehicle in the air. Santos-Dumont, who was the son of a wealthy Brazilian coffee planter, came to Paris from Sao Paulo in 1891, with the intention of studying the development of the automobile and to investigate the question of the balloon as a navigable craft. He made his first ascent in a free balloon in 1896 and immediately began experiments with a dirigible craft, his aim being to apply the type of petrol engine then used in light automobiles to the propulsion of an airship. In 1898 he completed his first airship, which was an ellipsoidal balloon 82·5 ft. long and 11·5 ft. in diameter equipped with two small tricycle motors consuming volatile liquid fuel and mounted in tandem to drive a single shaft—an arrangement which, by the elimination of every unnecessary part, provided 3·5 h.p. for a weight of some 66 lb. It may thus be said that he was the first to apply the internal combustion engine in a practical form for use in aerial navigation (Haenlein had employed an engine using gas from the balloon as fuel), and this some five years before the first flight was made by a man in a heavier-than-air machine, *i.e.* the Wright brothers' first flights on December 17, 1903. A trial of the airship was made from the Jardin d'Acclimatation, Paris, on September 18, 1898, but it was damaged by contact with a tree. A subsequent trial indicated the practicability of the means of propulsion though a premature descent was necessary owing to deflation of the envelope.

The experience gained with the "Santos-Dumont No. I" was used by the inventor in the construction of a second airship, and his accumulation of further practical knowledge, coupled with almost unlimited funds for experimental work, led him to construct no less than fourteen airships. His first considerable achievement was the winning of a prize of 125,000 francs offered by M. Deutsch de la Meurthe for the first flight from St. Cloud round

* The automobile was being developed intensively during the period 1896-1897, when road trials were undertaken.

the Eiffel Tower and return to the starting point (a distance of about 7 miles) in 30 min. On October 19, 1901, Santos-Dumont, after several attempts, and in spite of unfavourable wind, accomplished the circuit in his dirigible No. VI in 29 min. 31 sec. and provided a convincing demonstration of the efficacy of his means of propulsion—a petrol motor of nominally 12 h.p. It has been said that Paris was excited at, and the whole world keenly interested in, this event and its significance. In 1903 he performed another feat which appealed to the public imagination; he flew from St. Cloud to the Etoile, rounded the Arc de Triomphe, and continued, alighting near his own house in the Champ Elysées. During the same year in his dirigible No. IX he took part in the review of troops at Longchamps before the President of the Republic, so beginning an association between himself and the French Army which led to the application of the airship for military purposes.

It is said that Santos-Dumont, throughout his early experiments, believed that real success in aerial navigation would depend upon overcoming gravity by means of power in a heavier-than-air machine. Evidence of his faith in that principle is shown in his later experiments and his application of the box-kite form of construction in the aeroplane with which he achieved the first public flight with a heavier-than-air machine in Europe in 1906. He combined a romantic outlook with a love of mechanical detail, and it is understandable that, in his early activity, he surrendered to the attractions of the balloon already to hand, and that his best work was undertaken in the sphere of lighter-than-air aircraft.

The position at the close of the nineteenth century was that the navigable lighter-than-air vessel had been formulated by Meusnier and Cayley; a shape had been evolved which would reduce resistance to passage through the air; and controls, in the form of vertical and horizontal rudders, had been applied. The important problem of how to maintain the gasbag fully distended, in spite of leakage of gas, had been practically solved by the introduction of the ballonet inflated with air by a blower as required. The airscrew had been adapted with success, and finally, the internal combustion engine using a volatile liquid fuel had been applied for propulsion. Further progress depended on the perfection of the small high-speed petrol motor, which development had a momentous bearing on the future of flight, as in a few years the weight of this type of engine was reduced from nearly 100 lb. per horse-power to less than a tenth of that weight. Progress depended also on the development of a technique of airship construction—of advance on more or less definite lines.

Airships are classified under three headings: non-rigid, semi-rigid and rigid. The terms " non-rigid " and " semi-rigid " are applied to such airships as have fabric envelopes which depend for the maintenance of their correct shape in whole or in part on the pressure of the gas contained therein, which pressure is generally kept above that of the air outside by means of an air ballonet partly inflated and free to expand or contract in accordance with the amount of air supplied to it. The former is merely an elongated balloon and the latter an elongated balloon with a spar or stiff framework situated longitudinally within or below the envelope to which it is attached in such a manner as to distribute the load equally, so avoiding any tendency to longitudinal compression and consequent deformation of the envelope. The chief characteristic of these types is that the system of construction is restricted to comparatively small vessels, whereas, as will be seen later, the rigid type is

capable of being developed to very large vessels with higher speed and much increased range of operation.

Non-rigid and Semi-rigid Airships

It is understandable that the first practical airships should have been constructed in France, the country where the balloon originated and where the earliest experiments in aerial navigation were made. France led during the first years of the development of non-rigid and semi-rigid vessels which began with the twentieth century, and a tradition was established in regard to the use of those types which has continued to the present day, so that we find no construction of rigid airships in that country. The century opened with the experiments of Santos-Dumont, who by flying his series of small airships acted as a popular and sporting exponent of airship work. At the same time Count Ferdinand von Zeppelin was proceeding in Germany to explore the unknown potentiality of the rigid system of construction. Apart from those two phases of activity, very little was being accomplished, and from the scientific standpoint it cannot be said that the designs of Santos-Dumont were of any marked significance in the development of the airship, but they were the beginning of the movement in France which was directed to the perfection of the non-rigid and semi-rigid types with which we are now concerned; the origin and development of the rigid airship will be described later. Santos-Dumont constructed in all fourteen non-rigid airships during the period 1898–1905 and in 1904 he published a book describing his experiments.* It is of interest to note that early in 1904 he predicted that the airship would be found useful in observing submarines below the surface of the sea, and that it might be used for dropping " dynamite arrows."

The first airships constructed in France which may be said to have had any real influence on progress and design, subsequent to the historic achievements of Giffard and Renard were the series of ships built by MM. Paul and Pierre Lebaudy, sugar refiners, whose factory was at Moisson, near Roche-Guyin (Seine-et-Oise). The first ship was completed by the end of 1902, and had a length of about 190 ft., and greatest diameter of 32 ft., with a capacity of about 110,000 cu. ft. A Daimler (sometimes stated to be a Mercédès) engine of 35 h.p. supplied power to two airscrews 8 ft. in diameter, giving an air speed of 26 to 28 m.p.h. In all Lebaudy designs the car was short and was suspended from a long keel, which itself was suspended close under the envelope, and was generally covered in with fabric along the sides. The rear end of the keel terminated in vertical and horizontal fixed plates and controlling surfaces, while the tail of the envelope also carried small vertical and horizontal fins. The first Lebaudy airship was altered and reconstructed so many times that it is difficult to trace its exact history, but it was flown periodically from 1903 to 1906, when it was acquired by the French Government, and was used during military manœuvres in 1908 and 1909 (see Plate X).

The second Lebaudy airship, which became the second unit of the French air fleet, was the " Patrie," constructed during 1906, and it was wrecked in 1907. The " République " followed during 1907–1908, and it also was wrecked when returning from military manœuvres during September 1909—all on board losing their lives. The first of these losses was due to the

* " My Airships—The Story of My Life," by Alberto Santos-Dumont, London, 1904.

airship breaking from her moorings and drifting out of control, and the second was caused by the breakage of an airscrew blade and consequent ripping of the envelope. Later ships were the " Russie " (sold to Russia), the " Liberté," the " Capitaine Maréchal " and the " Selle de Beauchamp." They represented a definite advance in development and the main difficulty, *i.e.* that of suspending a heavy car from a long elongated balloon, was overcome by employing a rigid structure to distribute the load; it was built into the underside of the envelope and the head resistance was thus much reduced and a convenient support for the control surfaces provided. Cruciform fins were fitted to the rear end of the envelope to assist directional stability and they were characteristic of the later Lebaudy designs. Leakage of gas was a common fault, and though ballonets were provided to compensate for the loss, there was frequently distortion of the envelope, as may be seen in photographs of these airships. The larger the vessels became the greater the difficulty in manœuvring and mooring, and it was quite clear from the outset that an airship on account of its bulk was particularly subject to adverse weather conditions.

In spite of these difficulties and mishaps the performance and scope of operation of the semi-rigid airship were considerably advanced during the period 1903–1909. Progress was not aided by the invention of the aeroplane in 1903 and its subsequent development in Europe. Just as the invention of the balloon in 1783 had discouraged further investigation in regard to heavier-than-air flight, so the invention and successful development of the aeroplane eclipsed the airship and it is fairly certain that some of the support it might otherwise have had was diverted. This did not apply so much to the rigid airship of Count Zeppelin because, as will be seen later, its scope and purpose were better defined.

Next in importance, so far as influence on development in France is concerned, comes the series of airships built by the Astra Société des Constructions Aéronautiques at Billancourt (Seine). The first was the " Ville de Paris," constructed in 1904 and wrecked in 1906, but repaired in 1907 and delivered to the French Government in 1908; a flight of 147 miles in 7 hr. 6 min. is credited to this ship. It was followed by some dozen others, constructed for the French and foreign Governments, most of which had fairly good streamline-shaped envelopes from which were suspended long girder-shaped structures which served to distribute the weight; they were thus also of the semi-rigid type. The most important influence exerted by the Astra Company was, however, the adoption in 1911 of the " tri-lobe " section design of Senor Torres Quevedo, which became known as the " Astra-Torres " design. The purpose of the tri-lobe or trefoil section envelope was to give rigidity, and it also enabled the rigging and suspension of the car to be enclosed, thus reducing head resistance and making it possible to place the car close to the envelope. The whole design was intended to prevent deformation without the necessity for any girder structure to distribute the weight, and when properly inflated it gave considerable rigidity. The Astra-Torres system was adopted by the British Government for small airships during the later war period (1914–1918) with considerable success (see Plate X).

Other firms of note in France were those known as Maisons Clément-Bayard and the Société Zodiac. The former was established by the automobile manufacturer M. Clément at Levallois-Perret and constructed airships

generally similar to those of the Société Astra. The latter, operating at Puteaux (Seine), built a series of small semi-rigid airships intended for sporting and also for military purposes, which was the declared aim of airship development at this period. They could be transported in a single vehicle, could be inflated from a few bottles of compressed gas, and could manœuvre for some 6 hours at speeds comparing favourably with the larger standard types. When the reconnaissance terminated, the airship could be packed up and sent to the rear in the space of an hour, whereas this could not be done economically with large airships on account of the volume of hydrogen required if such a ship had to be reinflated for each service flight. It was held that the mooring of an airship in the open during war required an amount of preparation and attention which would be a serious drawback to keeping such a vessel inflated, while the method of operating from a base at a distance behind the front would, on each occasion, double the work which the airship had to perform. The Société Zodiac has an unbroken record in the manufacture of balloons and airships in France from 1906 continuing throughout the war period (1914–1918), and it is to-day concerned exclusively in the production of lighter-than-air aircraft.

The development and construction of airships proceeded in France continuously from the time of their inception and a government factory was established at Chalais-Meudon, near Paris, where much of the pioneer work had been undertaken. From 1914 to 1918 construction was solely for military and naval requirements; the last airship of official design was produced there in 1918. During recent years development in France has been confined to comparatively small non-rigid ships mainly for military, naval and training purposes. It is significant that the country in which the first airships were produced has not departed from the fundamental characteristics of the original type and has even reverted to the approximate dimensions of the early airships, though the performances are of course, much increased. Maximum speeds of about 65 m.p.h. and ranges of about 9 hours indicate the progress which has been made since " La France " made her historic short flight at 15 m.p.h.

In Great Britain, as in the case of France, the earliest activities were the result of private enterprise, and the undertaking of research and experiment on an official basis, with a view to the development of the airship for military purposes, came later. Prior to the war period (1914–1918) activity in regard to the construction of airships was confined to the production of a few small ships mainly for advertising and commercial purposes, and to a very restricted programme of official building for naval and military purposes. It cannot be said that Great Britain occupied a position of any prominence in the early development of the airship. Several privately-owned small airships were constructed from the year 1902 onwards. One of these was built by the balloon manufacturers Spencer Brothers, at their factory at Highbury, North London, in 1902. In 1905 the construction of a series of five small airships by Messrs. Willows and Co. was begun, the work continuing until 1914. Though these ships were successful, as testified by numerous flights of considerable duration, it cannot be claimed that, in the light of contemporary development abroad, they represented any marked advance in general design. The outstanding feature was the introduction by E. T. Willows of swivelling propellers as an auxiliary for the control of an airship in the horizontal and

vertical planes. The patent for this device was later acquired by the British Government and applied in the construction of service airships.

The construction of airships for military and naval purposes was begun in 1907. The first was a cylindrical semi-rigid of 50,000 cu. ft. capacity fitted with a 50 h.p. Antoinette engine and was named the "Nulli Secundus." In October 1907 it established a record by travelling from Farnborough to London, some 50 miles, in 3 hr. 25 min. It was followed by "Nulli Secundus II" (1908), "Army Airship IIA" (1910), the "Beta" (1910)—which was the first airship to carry wireless—the "Gamma" (1912), and the "Delta" (1912). These airships were manned by crews of four or five and were noticeably lighter in construction than their contemporaries abroad, and though they were not distinguished for any very conspicuous performances, their development provided useful information. The "Eta" (1913) is of special interest because it incorporated a new method of attaching the car suspensions to the envelope. Hitherto the airship cars had been suspended from a "rigging band," which was merely a rope or canvas reinforcement of the envelope, the method which had superseded the net used on the earliest dirigibles. The essential feature of the new system was known as the "Eta patch" and consisted of a steel ring having several strips of silk or cotton webbing passed through it, which were sewn or stuck to the envelope with a piece of fabric, forming a patch. The rigging ropes were attached to the ring and patch, which could be placed anywhere on the envelope.

On January 1, 1914, all the British official airships, irrespective of type, were handed over to the Royal Naval Air Service for operation, and in accordance with the policy laid down, further development was placed under the control of the Admiralty. At the beginning of the war (1914–1918) the British naval authorities quickly realized the need for a large number of small airships to serve as a protection against submarines. The need became acute early in 1915, and the war-period development of pressure airships may be said to date from February of that year, when the Admiralty decided to build numbers of small ships for anti-submarine patrol and food convoy duties—extreme simplicity of design to permit of rapid production in large quantities being demanded. As a result of this necessity the first series of non-rigid airships was produced—a series which soon demonstrated that, in regard to the design of this type, Great Britain excelled. The non-rigid type was selected as being most rapidly constructed and the first experimental ship actually undertook a trial during March 1915 (less than one month after the decision to build had been made), the envelope employed being that of an early airship and the car consisting of the fuselage of a B.E.2c aeroplane with existing engine and tractor airscrew. The airships which followed this successful experimental vessel were constructed under a series of classifications beginning with the S.S. (sea scout) type, popularly known as "Blimp," followed by the S.S. "P.," S.S. "Zero," C. (coastal), C. "Star," and N.S. (North Sea) types. They were numbered from No. 1 consecutively in each class.

The C. (coastal) type airship appeared towards the end of 1915; it was intended to be faster and to undertake more extended patrols, and it carried a crew of five with additional armament and a gun mounted on the top of the envelope. The envelope was of the Astra-Torres trefoil section already described, and had a capacity of 170,000 cu. ft. The power was provided by

two engines mounted in the car; one of 220 h.p. forward and the other of 100 h.p. in the rear. The speed was greater than in the earlier types, and the endurance considerably increased—over 24 hours being recorded on one occasion. It is of interest to note that one of these airships was in continuous commission for 2 years and 75 days, during which period over 66,000 miles were flown at an average of over 3 hours flying per day.

In 1916 the largest of the British non-rigid airships, designed during the war period, made its appearance. This class, known as the N.S. (North Sea), was evolved to operate directly with the Fleet and to carry out general convoy duties. The Astra-Torres type of envelope was again employed, but the capacity was increased to 360,000 cu. ft., the length being 262 ft., the breadth 57 ft. and the height 69 ft. A completely enclosed car 35 ft. long and 6 ft. high was used, windows and portholes being provided. The front portion was devoted to control and navigation, and the rear to a wireless cabin and sleeping accommodation for a crew of ten. Two engines, each of 240 h.p., were carried in separate cars, the access to which from the main car was made by means of a wooden gangway supported by wires. An original feature of the design of the N.S. class was the supporting of the fuel tanks and other weights directly on the envelope, and not on the car, in order to obtain as uniform a distribution of total load over the envelope as was possible. The N.S. class probably represents the highest development of non-rigid airship construction which has yet been attained—a design which is thoroughly airworthy and successful. Many notable performances are recorded and flights of over 30 hours were of common occurrence, the normal endurance at full speed—about 58 m.p.h.—being 24 hours. In 1919, however, the N.S.11 made a continuous cruise lasting 101 hours, during which time it is stated that 4,000 miles were traversed. The performance was an advance on that achieved by any other lighter-than-air aircraft and it remains to-day the record endurance for an airship of the non-rigid type. No further development of the non-rigid design has taken place in Great Britain. The type is naturally limited in size, and this constitutes a restriction of its use as a practical, and at the same time economical, vehicle for transport by air.

In Germany serious development of non-rigid and semi-rigid airships did not begin until 1906, owing probably to the fact that she was virtually committed to the principle of the rigid design as first introduced by Count Zeppelin in 1894. The construction of non-rigid and semi-rigid ships which began in 1906 may have been due in part to the wrecking of the second Zeppelin, which resulted in some lack of confidence as to the practicability of the rigid airship. The work began on an official basis under the supervision of Major von Gross, the officer commanding the government balloon construction establishment at Berlin, and also semi-officially under the direction of Major August von Parseval. It will be seen that, unlike the earlier activities in France, such private enterprise as existed had very little influence on the course of development in Germany.

The Gross airships were built in great secrecy, and very little reliable data is procurable about the earlier vessels. They were known as the "M" and also as the "Gross-Basenach" types, after Major von Gross, and they were designed by Oberingenieur Nikolas Basenach. "Gross I" was flying by July 1907, and it made a cruise of 3·5 hours, in company with the first Parseval airship, during an inspection by the Kaiser. The general design was

on the same principle as the French Lebaudy, though the external form was entirely different, there being an articulated steel tubular keel framework suspended below the envelope and serving to take all longitudinal compressive stresses, due to the car suspensions, while at the same time leaving the envelope practically free to take up its desired shape in pitching; the design was thus semi-rigid. The speed was about 15 m.p.h. When rebuilt as the second Gross airship the power was increased, two 75 h.p. engines being fitted. The capacity was increased to some 170,000 cu. ft. and the speed was stated to be some 28 m.p.h. This ship was known as " M.I." Four more were constructed prior to 1910, but results were not very satisfactory, and at this period the authorities began to lose interest in the semi-rigid airship due to the continued success of the rigid type which was being rapidly developed in the hands of Count Zeppelin.

The outstanding feature of the famous Parseval series of airships was that, at that time, they exceeded in capacity any ships other than those of rigid design. Prior to the war period (1914–1918) they were built by the Luftfahrzeug-Gesellschaft m.b.h., Berlin. A technical society for the study of airships, the Motorluftschiff-Studien-Gesellschaft, was formed at the instigation of the Kaiser, and a committee was appointed to acquire an experimental airship of the most promising type, Major von Parseval's first airship being finally selected. A characteristic feature of the improved Parseval design was its portability. Most of the contemporary so-called non-rigid types distributed the load by means of a long girder which served also as the car. Parseval used a comparatively small car and distributed the weight by hanging the car further from the envelope than usual; two ballonets were employed, one at each end of the envelope, facilitating trimming. Another feature was that the valves were operated automatically, this being found the most satisfactory and reliable method. Yet another feature was the use of a suspension system, which allowed a certain amount of movement to the car, which tended to damp out pitching moments set up by changes in the airscrew thrust and alteration in the position of the centre of gravity. The earlier airships had collapsible airscrew blades to facilitate packing.

Nearly thirty Parseval airships, the earlier being designated P.I., P.II, etc., have been constructed in Germany, generally for military purposes, since the inception of the design in 1906, and numbers were supplied to foreign governments. In 1913 the Parseval organization produced an airship which represented an important advance in that the hull and envelope shape was evolved as a result of research undertaken in a wind tunnel at Göttingen with a view to determine a form having a minimum resistance. The resulting envelope was the best streamline shape that had so far been produced, and it is significant that in ratio of length to diameter this type was almost identical with the best post-war practice in British rigid airship design. A Parseval airship of the type embodying this marked advance was acquired by the British Government in 1913; it had a capacity of about 310,000 cu. ft., a length of 276 ft. and a maximum diameter of 49 ft. Two Maybach engines of 170 h.p. each were fitted, giving a speed of about 45 m.p.h., the crew consisted of nine persons. This airship was employed during the early war period and saw considerable service. The Parseval airship designated P.L.19, built in 1914, was the first ship actually to be used on service during the war period (1914–1918). It was destroyed during a bombing flight.

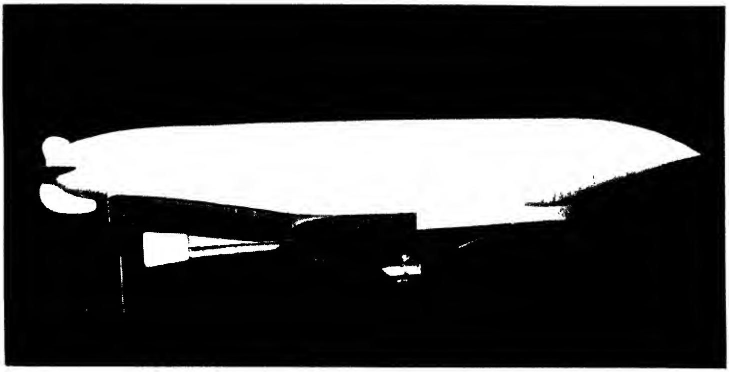
The development of pressure airships in Italy appears to have begun in 1907, stimulated, at its inception, by the success achieved in France and Germany. The semi-rigid type of construction was adopted and retained throughout the period of active development, which extended until the year 1924 when the construction of airships on an official basis was abandoned. The first airship actually to fly in Italy was constructed under the direction of the Ministry for War by a specialist unit of the Corps of Engineers in which Captain (later General) A. Crocco with his collaborator Ricaldoni had some years earlier begun research in aeronautics. The vessel was an experimental one, intended—as most of the early airships—for military purposes. It had a capacity of 90,000 cu. ft. with a large air ballonet, and proved quite successful, being launched in 1908, and attained, it is said, a speed of 35 m.p.h. From this experimental ship two types were evolved and regular construction was begun. The first type, known as the P. (small) type, had a capacity of 180,000 cu. ft. and the second, known as the M. (medium) type, had a capacity of 430,000 cu. ft. A special feature of these airships was the division of the envelope transversely into seven compartments with the double object of preventing an entire loss of gas in the event of damage to a portion of the envelope, and also to prevent "surging" of the gas, *i.e.* the tendency to collection of gas in that portion of the envelope which may be highest, thus rendering a return to the normal horizontal position extremely difficult. The two types had an efficient system of car suspension and envelopes of good streamline shape. The improved design incorporated an articulated keel, stiffening of the nose, automatic gas valves and adjustable pitch propellers.

Another line of development was being followed by the engineer Forlanini, who formed a company to build semi-rigid airships to his design. The first of these vessels, which was named the "Leonardo da Vinci," had a capacity of 132,150 cu. ft., and was propelled by a steam engine. The third Forlanini airship of 500,000 cu. ft. was ordered by the British Government and was under construction in 1914, but was subsequently taken over by the Italian Army. The design of these airships differed from that of the official P. and M. class in that the construction of the keel was different, and the gas was contained in separate bags, all enclosed within an outer cover, the space between the gasbags and the outer cover constituting an air ballonet. This arrangement of separate gasbags was generally similar to that originated by Count Zeppelin, and later adopted in all rigid airships.

After the war a large airship named the "Roma" was constructed. It was designed for transatlantic service and had a capacity of 1,200,000 cu. ft., being 410 ft. long, with a maximum diameter of 75 ft., and was provided with eleven separate gas compartments and six air ballonets. Six engines were employed producing a total of some 2,100 h.p. and a maximum speed of 68 m.p.h. At the normal cruising speed of 56 m.p.h. a range of 3,000 miles was said to be possible. Accommodation for twenty-five passengers was provided, and the airship was estimated to transport a useful load of 10 tons for 600 miles. The construction of this vessel served, it was claimed, to demonstrate the possibility and convenience of the semi-rigid type in comparatively large sizes, but it was unfortunately destroyed by fire during February 1922, as a result of loss of control and contact with high-tension cables, after being acquired by the United States Army.

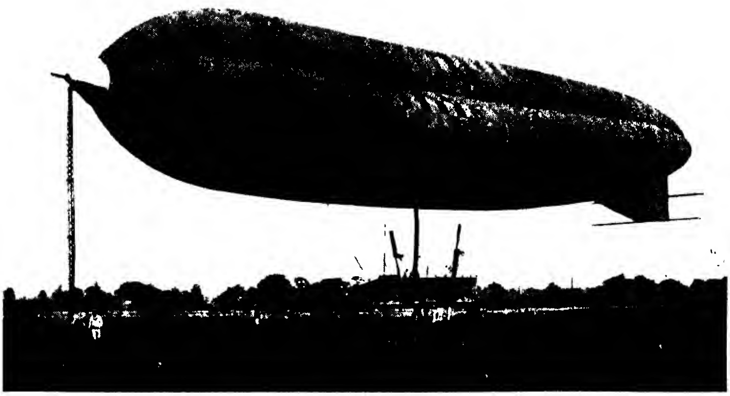
The history of the "Norge" (N.1) is of considerable interest. The

PLATE X



Lebaudy Airship, 1904

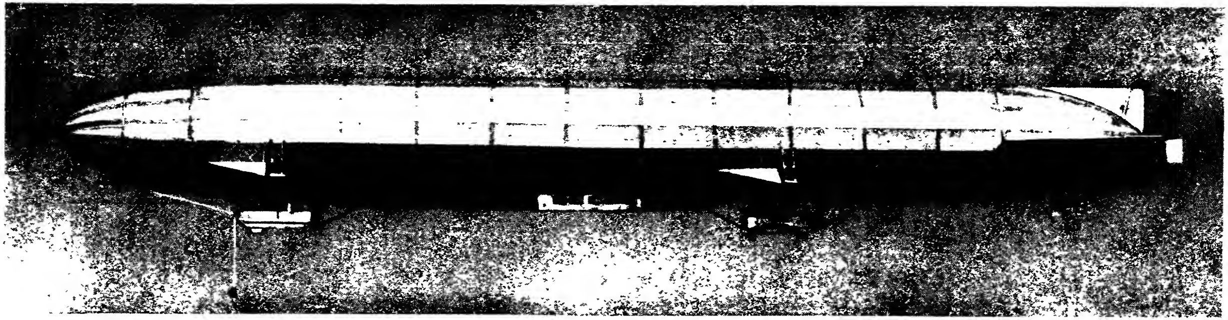
A type which had a considerable influence on progress and design following the earlier historic achievements. In June 1905 it made a record flight of over three hours. *See Page* 50



Astra Torres Airship, 1913

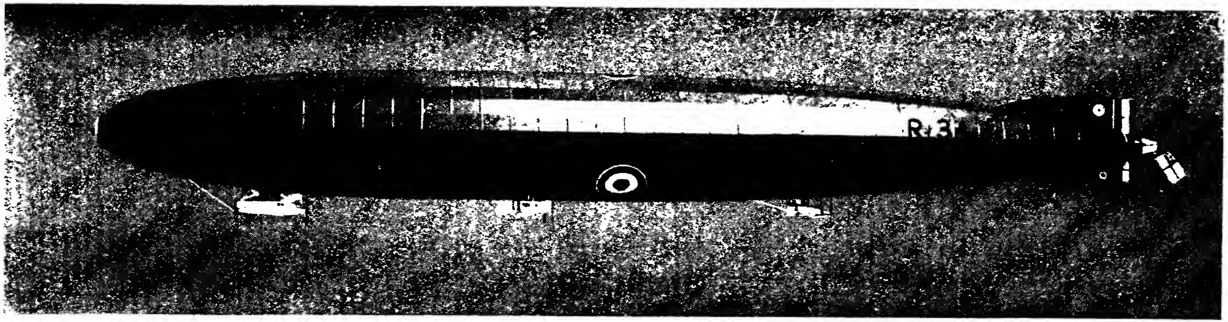
The "tri-lobe" system of construction was an important advance and it was widely adopted. *See Page* 51

PLATE XI



Zeppelin Airship "Sachsen," 1913

One of several airships employed in Germany for civil transport during the period 1910-1914, when nearly 35,000 passengers were carried and some 17,000 miles flown (See Page 60)



H.M. Airship R.34, 1918

The first lighter-than-air aircraft to cross the Atlantic, the journey being made on J[illegible] 2-6 1919, from [illegible]rtune, Scotland [illegible]neola, Long Isl[illegible]. The return flight was made in [illegible] days-seven h[illegible]

airship was acquired by the explorer Amundsen and was employed by him for a journey of exploration to the North Pole during 1926. The expedition started on May 11 from King's Bay, Spitzbergen—the airship having previously flown from Rome *via* England—and it reached the Pole successfully at 2 a.m. on the following day, having traversed about 800 miles. Observations were made and flags were dropped from a height of a few hundred feet. The return journey was directed to Nome in Alaska, a distance of some 2,000 miles, but owing to thick cloud and fog some difficulty was found in maintaining the proper course. On May 13 it was found that ice was forming on the envelope, and portions became detached and, fouling the propellers, punctured the envelope, causing loss of gas. Patching was undertaken, but when the supply of the necessary material was exhausted a landing was unavoidable, and this was made at 8 a.m. on May 14 at Teller, only some 90 miles from the proposed destination.

It is of interest to note that this landing was carried out successfully at a place where no preparations had been made, and as an example of a forced landing under such conditions it reflected the skill of those directing the operation, of whom the designer Nobile was one. Direction of the operation from the ground was actually undertaken by a member of the crew who had previously descended from the airship by parachute for that purpose. Following the successful landing, the ship was deflated and packed for transport to America, this being made possible by reason of the construction of the keel in several sections. During this remarkable cruise a total distance of about 3,000 miles was traversed in 71 hours, and valuable experience was gained concerning the operation of a large airship under very difficult conditions.

A second polar expedition by airship was carried out in 1928 under the leadership of General Nobile, but it ended in disaster. The vessel employed was N.4, which was named the " Italia " and was of the same design and dimensions as the " Norge."

The history of the airship and its development in the United States of America may be said to date from 1904, when the dirigible " California Arrow " was constructed by Captain Thomas Scott Baldwin of the United States Army. The airship resembled closely the earlier designs of Santos-Dumont in that it had a long rigid structure, which constituted the car, suspended beneath a cylindrical envelope. This rigid structure accommodated a power unit driving a tractor airscrew, a front double elevator plane, and vertical and horizontal rudders in the rear. The engine, which had four vertical cylinders, was specially constructed by Glen H. Curtiss for installation in the airship. The " California Arrow " was exhibited at the World's Fair at St. Louis in 1904, and proved very successful.

Subsequent activity was due also to private enterprise. In 1906 Walter Wellman, an explorer, had a semi-rigid airship constructed in Paris which he named " America," and in 1907 he attempted a flight of exploration to the North Pole from a base at Spitzbergen—an attempt which, however, was soon abandoned. In 1909 another attempt was made, but Wellman was again forced to turn back, and subsequently gave up the project. The " America " was later rebuilt to provide a capacity of 350,000 cu. ft., with a lift of 6 tons, and was fitted with two engines. During October 1910 an attempt was made

to fly the Atlantic, but it ended in the total loss of the airship. These experimental flights, though unsuccessful, were of value as showing the many difficulties and problems which had to be faced in the extended operation of an airship. A long guide-rope of steel, called the "equilibrator," was employed, but proved unsatisfactory over rough water, putting a considerable strain on the car as a result of the rope jumping from wave to wave. The cooling and consequent contraction of the hydrogen at night, and the danger of ignition from exhaust gases, were factors which were also found to require special consideration.

During 1910–1911 Melville Vaniman constructed a larger airship, the "Akron," with which he proposed to undertake a transatlantic flight. The ship made a number of successful trials, but on July 2, 1912, it became ignited while in flight from an unknown cause, and was destroyed with the entire crew of five men. As already recorded, a similar disaster overtook, in 1922, the Italian-built airship "Roma"—which had been acquired for the United States Army in 1921—and resulted in the loss of thirty-four lives. It may be said that this disaster had an adverse effect upon the development of large airships—at least in America—and strengthened the opinion that the non-rigid and semi-rigid types when constructed on a large scale could not compete with the rigid design so well conceived by Count Zeppelin. The construction of small non-rigid airships, primarily for experimental and training purposes, has however continued in the United States and by 1931 a fleet of some five vessels was in commission. These airships, constructed by the Goodyear-Zeppelin Corporation, employ the non-inflammable gas helium as a lifting agent, and the first non-rigid vessel so filled, the "Pilgrim," is now preserved in the United States National Museum at Washington as a record of this important development.

An interesting development which has recently taken place is the construction by the Metalclad Airship Corporation of an all-metal airship of small size. The envelope of this airship is constructed of duralumin sheet 0.008 in. thick, the various sheets being joined together by three rows of small rivets spaced 0·25 in. apart. It is claimed that the metal envelope so constructed is satisfactorily gas-tight. Research on these lines was begun in 1922, and the first experimental vessel, the Z.M.C.2, was completed in 1929, and delivered to the United States Navy during September of that year.

In view of all the activities which have been described, which obviously involved considerable expenditure of money and so frequently ended in disaster, it may well be asked what are the advantages of the non-rigid and semi-rigid types of airship and their use. The advantages of the former were found to be simplicity of construction, lightness, and ease of dismantling and of transport, but all these are discounted by the fact that the design has been found unsuitable for ships exceeding about 500,000 cu. ft. capacity so that it is confined to relatively small airships. As the size and load increases it becomes impossible to distribute the weight in such a way as to avoid deformation of a non-rigid envelope, and for this reason the immediate post-war development was concerned with the improvement of semi-rigid design. The maximum possible increase in size of the semi-rigid type was, however, in all probability, reached in the ill-fated "Roma," and it is very unlikely that such airships will be constructed in future exceeding 1,000,000 cu. ft. in capacity. For the purposes of transport by lighter-than-air aircraft on a commercial basis, which

involves the use of large vessels, the rigid form of design is most suitable, and it is certain that further progress will be wholly on those lines. The development of the non-rigid and semi-rigid airships to-day is confined to small ships intended mainly for naval and military purposes, for observation, training and transport on a small scale.

Rigid Airships

It has been seen that the German engineer David Schwarz originated the rigid type of airship in 1897, but the credit for the initial development which began in 1898, and its subsequent perfection, belongs to that great pioneer of airship construction, Count Ferdinand von Zeppelin (1838–1917); he was the first to devise a practical means whereby an airship could maintain its shape under all conditions. Briefly the construction was that of a stiff framework built up of girders, over which a fabric outer covering was stretched, the buoyant gas being contained in independent gasbags inside at a pressure usually not above that of the surrounding air. His method of construction, which has been largely followed by other designers of rigid airships, incorporated a series of transverse metal girders joined together by other girders, known as longitudinals, running from the nose to the tail of the ship. Reinforcement of the structure at the nose to resist the air pressure in flight, and at the tail in order to carry the control surfaces, was a necessary feature of the design. A gasbag containing hydrogen was placed between each pair of transverse frames, the bag being confined in its proper compartment by wiring across each separate frame. The gasbags were open at the bottom and floated freely to rest against the top and sides of their compartments. A space was available, below the gasbags, which ran the whole length of the airship and provided a gangway for the movement of the crew and passengers within the vessel, and gave access to the various cars suspended beneath or attached to the keel, and also to the top of the airship.

The main problem in the construction of a rigid airship was the distribution of the various loads so that they were balanced against the lift of the hydrogen, or other lifting agent, and it was found that this was difficult to arrange. The additional structure weight at the bow and stern, the power units, the control car and the passengers' quarters were necessarily heavy units, the weight of which was localized, whereas the distribution of the lifting force was more uniform. Some adjustment of the load was found to be possible by distributing the engine cars along the length of the airship and by carrying the oil and fuel in a number of tanks placed at intervals along the ship. The centre of buoyancy in an elongated airship being at about the centre of the ship, which would be approximately the centre of volume, the balance of weight when the ship was properly trimmed should be so arranged that the centre of gravity would be below that point. It was found during flight that, with the loss of gas from various causes, and the consumption of fuel, it was necessary from time to time to readjust the amount of the disposable load in the form of crew, fuel and ballast in order to maintain the ship in correct buoyancy and trim—an important part of the technique of airship control and operation.

The early Zeppelin airships were, for reasons of convenience in construction, of a shape which incorporated a long parallel portion—the streamline

form, or better aerodynamic shape, being introduced at a later date. In consequence the power required to propel them, after making due allowance for size and speed of the later ships, was greater in the earlier designs, and this fact should be borne in mind when comparing the performance figures of early and later types. The use of controls in flight was found to induce large bending moments at the middle of the airship, and the structural problems involved in mitigation of the dangers resulting from such stresses required much research.

Count Zeppelin was born at Constance in Baden on July 8, 1838. He was greatly impressed by the use of free balloons during the American Civil War, and at the siege of Paris in 1870. He tried to interest the German Government as early as 1887, but it was not until 1894, when he was fifty-six years of age and had retired from an active military career, that he completed the designs for his first airship. The building of this ship (L.Z.1) was commenced in 1898, and it was launched on July 2, 1900; it had two engines of 16 h.p., and succeeded in reaching a speed of nearly 20 m.p.h. Apart from structural weakness and buckling of girders, it was generally successful, but Zeppelin realized the need for a larger and stronger ship with greater power. It took him five years to raise the necessary funds, being in 1905 financed by the King of Württemberg, and also by a manufacturer of aluminium. The second airship (L.Z.2) rose to a height of 1,643 ft., but was forced to land through engine trouble, and later a storm wrecked it. The opinion was largely held that the rigid airship, as developed, was impracticable, but Zeppelin, then sixty-eight years of age, put the last of his resources into the building of a third ship, completed late in 1906. This ship (Z.1) was immediately successful, the German Government became interested and offered to acquire a rigid airship if it could pass a 24-hour test.

Zeppelin constructed his fourth airship in 1908, and aroused enthusiasm throughout Germany by flying it, on its initial cruise, over the Alps to Lucerne, and back to Friedrichshafen. Unfortunately engine trouble forced a landing and a storm blew the airship out of the control of the emergency landing party, resulting in a rapid ascent and explosion from some obscure cause. This disaster did not dishearten him and he made a second public appeal for funds, resulting in the advance of some six million marks. He placed this money in trust, founding the Zeppelin Endowment for the Propagation of Airship Navigation, which subsequently controlled the Luftschiffbau-Zeppelin and other subsidiary companies. He had the gift of attracting able engineers to his side, and Dr. Hugo Eckener was placed in charge of the passenger-carrying subsidiary company* which during the period 1910–1914 carried nearly 35,000 passengers over various routes, covering some 170,000 miles without serious mishap. This was, of course, far in advance of any organized transport by aeroplane. Five airships were built for that purpose: the "Schwaben," "Sachsen," "Viktoria Luise," "Deutschland" and "Hansa," and hangars were erected at Berlin, Baden-Baden, Dusseldorf, Frankfurt-am-Main, Leipzig and Dresden. In all some twenty-five Zeppelin airships were constructed, or under construction, prior to the war, 1914. At this period the success achieved by Count Zeppelin encouraged other designers to come forward, the most notable of whom was Dr. Schütte of Danzig who in collaboration with Henrick Lanz evolved the Schütte-Lanz type of rigid airship, which had a wooden structure and a streamline form far in advance of any hitherto

* Deutsche Luftschiffart Actien Gesellschaft.

produced. The first vessel (S.L.I) appeared in 1911; it had a capacity of 700,000 cu. ft., with gas contained in separate bags, and was 430 ft. long, with a maximum diameter of 60 ft. Two engines were employed, developing a total of some 540 h.p., and the speed was stated to be from 43 to 50 m.p.h. This remarkable performance was due primarily to the much improved shape of the vessel as evidenced by the fact that, while the capacity was similar to that of the "Deutschland," the engine power was only some 20 per cent. greater. Later Schütte-Lanz airships were larger, and had even better performances, and there is no doubt that they had an influence on the later Zeppelin design.

With the advent of war German military authorities had high expectations regarding the fighting qualities of big airships, and an intense building programme was started. They were found, however, to be of little value for that purpose and most vulnerable to attack, but on the other hand they were extremely useful for scouting work with the Fleet, in patrol, reconnaissance, mine-sweeping and bombing operations. During the actual war period (1914–1918), the Luftschiffbau-Zeppelin designed and built 88 airships at its four factories, making a total of 113 ships from 1900 to 1918. After the war the Zeppelin Company built the "Bodensee" of 800,000 cu. ft. capacity, and instituted a commercial air service to Berlin, carrying 2,380 passengers and making 103 flights in 98 days. The company was also completing a second airship, the "Nordstern," when the Inter-Allied Air Commission took over these airships, assigning them to France and Italy, respectively, and forbade all further operations. It was due to this action that the Goodyear-Zeppelin Corporation for the construction of Zeppelin type airships in the United States of America was formed in 1924.

As already remarked, the Zeppelin airships constructed during the period 1914–1918 were used chiefly for scouting and aerial bombing, but for the latter purpose they proved less satisfactory than their constructors anticipated. It is of interest to note in passing that the first application for bombing was carried out against Antwerp on August 25, 1914, and the first raid over England took place on January 19, 1915. The use of hydrogen as a lifting agent rendered the airship a hazardous and far weaker weapon of offence than had been supposed, due to the employment of incendiary bullets by defenders. In all some fifty-three bombing raids were made over England during the war period, and the operations were limited to the hours of darkness, whereas the later employment of the aeroplane was not so limited. The value of the Zeppelin airships was much greater in the work of reconnaissance, particularly over sea, and it may be said that this was their principal function. The L.30, the first of the "super-Zeppelin" type, was completed in 1916, and launched on May 28. It had a maximum altitude, or "ceiling," of some 13,000 to 15,000 feet, depending upon the load carried and the weather conditions. The length was about 643 ft., and maximum diameter about 78 ft., with an overall height of nearly 92 ft. The gas capacity, when 95 per cent. inflated, was some 1,907,000 cu. ft., and the gross lift 57·8 tons, and disposable lift about 22 tons. The maximum speed was stated to be from 60 to 63 m.p.h. Later examples of the super-Zeppelin class had a disposable lift of some 40 tons—60 per cent. of the total lift—and the ceiling was increased to nearly 20,000 ft.

Count Zeppelin died on March 8, 1917, and thus failed to witness

a very remarkable flight by the L.59, which was launched on October 10, 1917. The L.59 was 744·5 ft. long, with a capacity of 2,381,000 cu. ft. of hydrogen, was equipped with five engines and had a disposable load of some 50 tons. On November 21, 1917, the airship left Jamboli in Bulgaria for the German East African Colonies with some 10 tons of stores and munitions for the relief of the military force there. After passing Khartoum the airship was informed by wireless that the force had surrendered, and thereupon returned to Jamboli, landing safely on November 25, having traversed a distance of some 4,000 miles in about 95 hours, without break in the journey and still retaining sufficient fuel for a further two to three days' cruise.

The activities were restricted by the Treaty of Versailles, which limited the size of German airships. The experience of the war period had shown clearly that increase in size was essential to the development of the rigid airship as a vessel capable of extended operation with safety and efficiency, but under the Treaty the construction of airships was limited to 2,470,000 cu. ft., which was approximately the size of the largest vessel constructed during the war period. Further progress in the construction of Zeppelin airships will be considered in the chapters devoted to the development of air transport.

It will be seen how Germanic is the rigid airship, both in origin and development. Only two other countries undertook construction, Great Britain and the United States of America, and the latter did not begin until 1919. Development in Great Britain dates from 1908, when owing to the remarkable performances accomplished by Zeppelin airships in Germany, the British Government decided to proceed with the construction of vessels of similar type, the responsibility for construction and subsequent operation being placed with the Admiralty. The first rigid airship built for the Admiralty was designed by Messrs. Vickers, Ltd. at Barrow-in-Furness during 1908–1909, and was completed in May 1911. This airship was known as " Naval Airship No. 1 " (or R No. 1) and received the unofficial name of " Mayfly." The length was 500 ft., and maximum diameter 48 ft., with curved bow and tapering stern, giving a capacity of 663,000 cu. ft. of hydrogen when fully inflated. The metal employed in the construction was duralumin, which had been introduced into England from Germany in 1909. The main structure followed the standard Zeppelin system, but the shape was aerodynamically superior and it was the first rigid airship to have all the control surfaces mounted at the rear. Unfortunately it was badly damaged and broke in two parts while being brought out of its shed on September 22, 1911, and further work on rigid airships was abandoned. The decision was made during February 1912, and the airship section was disbanded in March; it was, however, reconstituted during September of the same year, and was stationed at Farnborough as a training centre.

During the period 1912–1914 considerable advances were made in the development of Zeppelin airships in Germany—progress which has already been described—and this rendered a policy of inactivity undesirable, so that the British Government decided to resume construction of the rigid type. It is understandable that in regard to design Germany had a definite lead at that time. British designers had little experience to base their construction upon, and for some ten years were compelled to make use of such information regarding the Zeppelin practice as became available either through the capture

of vessels during the war period or from other sources. Nevertheless, no less than nine airships were built during the period 1915–1918 under the stimulus of war, and the last two, R.33 and R.34, which constituted a new class, marked a definite stage in development over the preceding ships, which all had a long parallel portion between the somewhat poor shape of the nose and tail portions. The R.33 and R.34 were designed from information made available by the bringing down of the Zeppelin L.33 in Eessx on September 24, 1916, in such a condition that sufficient structure and fittings, such as valves, etc., were usable as guide designs, the L.33 representing the latest type of the so-called super-Zeppelin. The British ships were at first intended to be faithful copies of the L.33, but improvements in design were incorporated as they became available through the salving of portions of later Zeppelins. At this period Great Britain was building only two ships on two cradles whereas Germany was completing thirty ships on four cradles. The R.33 was built by Sir W. G. Armstrong Whitworth & Co., Ltd., and the R.34 by Messrs. William Beardmore & Co., Ltd.

During 1919 the R.34 made history by being the first lighter-than-air aircraft to cross the Atlantic Ocean and the first aircraft of any sort to make the double crossing.* The airship left East Fortune, Scotland, on July 2, with a crew of thirty under the command of the later Major G. H. Scott, the outward voyage occupying 108 hr. 12 min. for a distance of some 3,130 miles, and the landing being made at Mineola, Long Island, U.S.A., on July 6. The return flight was commenced on July 10, and was made in 75 hr. 3 min. with the aid of favouring winds. The engines fitted were five Sunbeam "Maori," each of 250 h.p.

The historic crossing of the Atlantic by H.M.A. R.34 under weather conditions which were at times very unfavourable, served to demonstrate that the rigid airship was a practical vessel capable of transoceanic travel, and not merely a fine weather aircraft. Full particulars of the outward and return journeys are given in the diary of the flight—a document of very considerable interest.† The achievement has not always been given the full credit it deserved (*see* Plate XI).

* * * *

In concluding this short survey it is desirable to consider some of the factors governing the operations of airships. Lighter-than-air aircraft are, by their nature, highly subject to meteorological conditions, and for this reason frequent and accurate weather reports are absolutely essential for their successful operation. Meteorological conditions may affect the lift of an airship to a considerable extent; the rays of the sun acting directly on the envelope may raise the temperature of the gas above that of the surrounding air, and the buoyancy is thus increased, necessitating the discharge of gas, or flying with the nose down, to counteract it. Conditions may prevail in which the temperature of the air is less near the ground than at altitude, causing some difficulty while rising, due to the gas in the airship being at a lower temperature than the air above. The successful navigation of a large airship demands much skill and experience in order to take the fullest advantage of favourable weather

* The first crossing was made on June 14-15, 1919, by Sir John Alcock and Sir Arthur Whitten Brown on a Vickers-Vimy aeroplane.

† "The Log of H.M.A.R.34," 1921, by Air-Commodore E. M. Maitland, C.M.G., D.S.O., etc.

conditions, such as steering a course both horizontally and vertically which will make the best use of prevailing winds, the very considerable bulk of a modern airship being a factor mitigating against accurate navigation. The formation of a deposit of ice on the envelope, due to special weather conditions, may considerably reduce the buoyancy of the vessel, and such conditions have to be avoided.

The trim of an airship has to be maintained during flight by a judicious discharge of ballast or gas, from different parts of the vessel, and by the use of the dynamic controls. The control of the height may be effected by the use of the elevators, which can, of course only be effective while the ship is moving, their efficiency depending on the speed of the vessel, or by the release of ballast or gas, the aim being, however, to conserve these as long as possible.

The avoidance of storm centres, where very violent disturbances are present, is a matter of considerable importance, in so far as the conditions may render control impossible, or affect the structure of the airship. An ordinary storm should not affect the vessel in so far as the structure is concerned, but it will affect it in regard to the distance travelled over the ground in accordance with the strength and direction of the wind. The meteorological phenomenon known as a " line squall," may induce violent vertical air currents which will throw an airship out of the horizontal path and subject it to severe stresses which may cause structural collapse. The possible effects of such gusts is a matter for serious consideration by airship designers, and the problem of making the risk of structural collapse negligible under all conditions is of great importance. Atmospheric disturbances such as thunderstorms, cyclones and hurricanes are usually of local character and are generally avoided by a commander who has due warning of their approach. Lightning is a danger to non-rigid airships, owing to the absence of a metal framework sufficient to carry the electrical discharge, but experience with rigid airships has shown that the metal framework, together with the exhaust gases from the engines, form a conductor for the current and constitute an adequate factor of safety.

It is not possible to move a large airship into or out of its hangar except during comparatively calm weather or when the wind is blowing in line with the length of the shed. The problems involved in the construction of a revolving shed large enough to accommodate a modern rigid airship, and the prohibitive cost of such a structure, led to the introduction of the mooring tower or mast which permits the airship to approach from any direction and to be free, when moored, to rotate about the axis of the mast and also to rock vertically, thus responding freely to changes in the direction of the wind. Considerable experience has now been obtained in mooring airships in all weathers, the general procedure being to approach the mast slowly against the wind at a height of some hundreds of feet, when a mooring cable is thrown out and linked to a similar cable from the mast, the joined cable being then wound in by a winch at the foot of the mast, while the airship maintains a pull on it by reversed engines. Auxiliary cables, known as " side guys," are also employed, and when the airship is safely moored a gangway, fitting flush with the nose of the ship is let down, and rests upon a platform which runs round the masthead, providing access. Provision can be made for maintaining the trim of an airship at the mooring mast by the supply of ballast in the form of water, and of the gas used as a lifting agent, which are conveyed in mains running to the top of the mast. Balance weights may also be slung from the airship by cables

so that when the ship is horizontal the weights just rest on the ground and a fine adjustment can then be made by means of ballast, the weights acting as a restoring force in the event of sudden pitching. The successful operation of airships over long distances naturally required the erection of mooring masts at convenient points on the route, and several such bases were established in different parts of the world. Mooring masts were also erected on naval vessels.

In order to reduce the danger from fire, the non-inflammable gas helium was adopted as a lifting agent in place of hydrogen, though natural supplies of the gas are not widely available, and its buoyancy is slightly less than that of hydrogen. The use of helium in conjunction with engines using heavy oil instead of petrol provided adequate safety from fire, and it is probable that any future development will take place on those lines. The use of heavy fuel also represented a saving of weight on an extended flight.

The performance of an airship is a factor of great importance, if a regular commercial transport service is to be maintained with such vessels. The speed must be high as compared with the winds which may be encountered on any given route, and in practice it appeared that a cruising speed of under 75 m.p.h. was not of much value for a commercial service, and that a speed of at least 100 m.p.h. would be necessary for profitable operation.

When considering the history of the airship it is not easy to avoid the conclusion that, in the light of present-day knowledge, the principle on which it functions is not in application so satisfactory as that of the aeroplane. The airship derives the lifting force, and hence its support, from the difference in weight between the volume of air displaced by it and that of the gas contained within the envelope. This difference must be greater than the weight of the structure of the airship and its crew, etc., if it is to rise in the air and function as an aircraft. Obviously such a vessel will have considerable bulk and this is one of the factors which mitigate against easy and accurate navigation, because the airship is, by virtue of its size and lightness, particularly subject to weather conditions. Another factor which tends to hinder consistent operation is that the gas—the lifting agent—is affected by changes in temperature which cause alternate contraction and expansion, the latter resulting perhaps in some loss of gas. The weight of the volume of air displaced by the airship becomes less as it rises—were it not, the ship would continue to ascend indefinitely at a constant speed—and it is this fact which makes lighter-than-air aircraft practicable. But this very fact of the air being compressible means that it is also affected by changes in temperature and in consequence another variant is introduced. For these reasons the conviction arises that the principle of buoyancy is not so suitable for a vehicle moving in three dimensions when the medium of travel is the air, and if consistency in operation is to be achieved, it would appear that the principle of dynamic flight by means of surfaces acting on the resistance of the air—*e.g.* the aeroplane—is the better method.

VIII. MECHANICAL FLIGHT DEFINED AND FORMULATED

(1800–1898)

IN ORDER TO UNDERSTAND how the aeroplane evolved, we must return for a moment to the period of speculation and the imitation of nature which closed with the seventeenth century. The idea of human flight with artificial wings was then discredited and serious students of the problem accepted the arguments of Borelli that flapping-wing flight was impossible, though experiments on those lines persisted. That was understandable in view of the fact that the capabilities of rigid planes were then unthought of and a suitable engine, which could enable such planes to derive support from the air, was an invention of the distant future. For these reasons the eighteenth century was almost devoid of serious experiment, though a few men of science—notably the mathematician Charles Hutton—were conducting investigations concerning the resistance of the air to bodies moved through it, but such research was not undertaken with reference to the problem of mechanical flight.

The aeroplane belongs essentially to the nineteenth century because then it was defined and formulated; its realization came in the year 1903 as the result of knowledge accumulated over a period of about 100 years, the experience of gliding flight, and the advent of the internal combustion engine, the idea having developed gradually until the genius and persevering research of two men—the Wright brothers— made it an accomplished fact. Unlike other forms of transport, flight involved exploration in an element previously unexploited and it introduced problems far more abstruse than any of those connected with locomotion on land or on water; it presented difficulties so formidable that it constituted one of the great, if not the greatest, achievements of man in his continued effort to gain control over the natural conditions of his environment. Flight, as we have seen, was one of the earliest of recorded aspirations and for many centuries it remained so; then came the interlude of aerial navigation by means of the balloon, but the original problem was left unsolved. It is at that stage, the close of the eighteenth century, that we resume the inquiry.

The first step in the realization of an ideal should be to define it—to define its principle or the basis upon which the conception rests. Mechanical (heavier-than-air) flight had never, before the nineteenth century, been defined, and there is no evidence to show that those who aspired to it understood its fundamental basis, much less were they able to formulate the problem; true, Leonardo da Vinci wrote: " An object offers as much resistance to the air as the air does to the object "—which was a simple statement of the law of reactions as applied to flight—but the observation was not disclosed until 1797. If it is accepted that the definition constitutes the first step, the aeroplane was conceived by an Englishman—Sir George Cayley—and he deserves the title of " Father of Aeronautics " which he is sometimes accorded. For Cayley defined the " whole problem " of mechanical flight as being " to make a surface support a given weight by the application of power to the resistance of the air "—a definition which is classical in its import. It was a clear statement

of basic principles—a definition which explained also that ancient aeronautical device, the kite—and it was made in 1809 at a time when there was much confusion of thought on the subject.

Before considering in detail the work of Cayley and of others who helped to define and formulate the aeroplane, it is interesting to cite a second definition because it serves to clarify and to illustrate the historical development of the idea. In 1842 another Englishman, William Samuel Henson, described the principle of the flying machine, as he understood it, thus:

"If any light and flat or nearly flat article be projected or thrown edgewise in a slightly inclined position, the same will rise in the air till the force is expended, when the article so thrown or projected will descend; and it will readily be conceived, that if the article so projected or thrown possessed in itself a continuous power or force equal to that used in throwing or projecting it, the article would continue to ascend so long as the forward part of the surface was upwards in respect to the hinder part, and that such article when the power was stopped, or when the inclination was reversed, would descend by gravity only if the power was stopped, or by gravity aided by the force of the power contained in the article, if the power be continued, thus imitating the flight of a bird."*

This was an elaboration of Cayley's definition, in so far as it attempted to explain how the application of power to the resistance of the air was to be effected for the useful purpose of flight, *i.e.* it stipulated a flat or nearly flat surface with its forward part raised, so that the surface was to be inclined in its passage through the air. From this statement it is clear that the elementary principle of the aeroplane was established, in England at any rate, during the first half of the nineteenth century, and it remains to show how that principle was applied.

By far the most important contributions to the science of mechanical flight during that period were made by Sir George Cayley (1773–1857) who, as already remarked, has been described as the "Father of Aeronautics," and also as "*le plus grand génie de l'aviation*" and "*le véritable inventeur de l'aéroplane.*"† He was the first engineer and man of any scientific attainment to apply his mind fully to the problem of mechanical flight and to attempt to explain mathematically its fundamental principles. His exposition of those principles may be considered as the basis of the science of aerodynamics as it was subsequently developed, and his calculations, which are generally in accord with those since established, were the form of its expression. He countered the prevalent confusion of thought by the famous definition which has already been quoted, and it is no exaggeration to say that, by the end of his life, he had provided, for those who cared to use it, practically all the theoretical knowledge necessary—apart from that required to develop a suitable engine—for the accomplishment of flight. In considering his work we are indebted to Mr. J. E. Hodgson, who has done so much to elucidate it by his research and by the publication of documents previously not available.‡

* Henson's Patent Specification (No. 9,478), A.D. 1842.

† These words were employed by the eminent authority M. Charles Dollfus, and bear witness to the esteem with which Cayley's work is held in France.

‡ The most comprehensive survey of the life and work of Sir George Cayley is contained in "The History of Aeronautics in Great Britain," by J. E. Hodgson, 1924, and in a paper read before the Royal Aeronautical Society on January 6, 1936.

Sir George Cayley, the sixth baronet, was born at Scarborough—the ancestral home is nearby—on December 27, 1773 (*see* Plate I). Philosophy (in the then accepted sense) and scientific research appear to have attracted him from an early age, and it is said that his interest in the problem of flight was inspired by the invention of the balloon, which occurred when he was ten years of age. It will be appreciated that his contributions to the subject of aeronautics were more in the theory than in the practice, but his enunciation of principles was based on experiment, *i.e.* on verification by practical test; hence his method was that of a man of science. He states that his first experiments in aeronautics were made with a Chinese "flying top"—the primitive device referred to in Chapter III—in the year 1796. The device illustrated the principle of the lifting airscrew and Cayley subsequently improved it, devoting much time and thought to the matter as is shown by a sketch (1854) and an example—the best, he said, that he had ever seen and capable of rising as much as 90 ft. in the air when rotated rapidly by a cord wound round it. This flying top, which is apparently the only piece of Cayley's experimental apparatus remaining (his documents and sketches are preserved), has three flat metal vanes set at an angle of about 25 degrees to the plane of rotation and the leading portion of each vane is cut away to form a fine entering edge. It is significant that in several of Cayley's designs for aircraft he shows "steam-driven propellers" evidently based on the flying top—the difference being that in the case of the former (which presumably would be rotated at a much lower speed) four or five blades are shown and they are tapered (in plan) for attachment to the common axis.

From the year 1796, Cayley appears to have investigated the subject of flight intermittently until his death in 1857. He was concerned with both heavier-than-air and lighter-than-air flight, bringing the whole under the general term "aerial navigation," but the full force of his genius is shown in the former problem, and apart from his perhaps over sanguine opinion regarding the potentiality of the airship, it is clear where his preference and the weight of his judgment lay. We are concerned here only with his work in mechanical flight, his investigation of the problem of the navigable balloon having already been referred to.

Cayley's published writings were his most valuable contribution because they contained his best considered and so most profound statements; moreover, they were given to the world by publication, whereas that which is contained in his notebook, etc., has but recently been made available. His first finished contribution, an essay on "Aerial Navigation" (on this occasion specifically mechanical flight), appeared in Nicholson's *Journal of Natural Philosophy, etc.* in 1809–1810; it has frequently been quoted and was reprinted by the Royal Aeronautical Society in 1910. Cayley begins by observing that a watchmaker of Vienna named Degen was reported to have succeeded in raising himself in the air by mechanical means and it prompts him to state "the fundamental principles of this art" in the hope that he may thereby expedite the attainment of an object of such great importance that "a new æra in society will commence" from the moment that it is realized. He feels "perfectly confident" that it will be possible to transport persons and goods "more securely by air than by water, and with a velocity of from 20 to 100 miles per hour," and to realize this it is necessary only to develop a suitable engine. Perhaps Cayley was too confident and failed to realize the necessity for prolonged experiments

in gliding flight prior to the application of power, but it must be borne in mind that his conclusions were based on his research and calculations and were thus not in the nature of idle prophecy.

He considers Boulton and Watt's steam engine as a possible source of power, but " as lightness is of so much value " (in this problem) he turns to the " probability of using the expansion of air by the sudden combustion of inflammable powders or fluids," *i.e.* he sees a possible solution, in the internal combustion engine—a most profound conclusion, as history shows. He continues: " For the sake of perspicuity I shall, in the first instance, analyse the most simple action of the wing in birds . . . " and immediately draws attention to the phenomenon of gliding flight with wings extended motionless. A diagram of the forces operating on such a wing follows, and it is of interest to note that this diagram was also engraved by Cayley on a small silver disc, 1 in. in diameter, bearing his initials " G.C." and the date 1799, which has recently been found and is now preserved in the Science Museum. This relic provides conclusive proof that these particular investigations were made at least ten years before the essay, now being considered, appeared.

The diagram, as engraved by Cayley, is shown on Plate XII and it corresponds exactly with that reproduced in *Nicholson's Journal*. The longest line represents a section of the plane of both wings opposing the horizontal current of air created by the bird's motion, or the force of the wind blowing against it and indicated by the arrow. This force, " the whole force of the air under the wing, acting at right-angles to it," Cayley resolves into two forces: that which " sustains the weight of the bird " and " the retarding force by which the velocity of the motion producing the current will continually be diminished," represented respectively by the second and third sides of the triangle. Here we have a definition of what is now termed " lift," *i.e.* the force perpendicular to the flight path in the plane of symmetry, and " drag," or, colloquially, head resistance. Cayley is considering the wing only, and he points out that in addition there is the " direct resistance, which the bulk of the bird opposes to the current," *i.e.* what is now termed " parasitic drag," and that it should be considered separately. The exposition is sometimes difficult to follow as Cayley employs the somewhat stilted language of his time, but the reasoning is fundamentally sound. In a subsequent passage he describes the diagonal bracing of wings and the advantage of " the poles [spars] being couched within the cloth, so as to avoid resistance," and also that an upright shaft opposing the current should be of " a flat oval shape having its longest axis parallel to the current." From this it is clear that he appreciated the importance of streamlining.

There follows the famous definition of the " whole problem " already quoted and he proceeds to a consideration of the " resistance " (the word is used for both " lift " and " drag ") of different sized surfaces moving at certain velocities, and is dissatisfied with the existing tables of " angular resistance." He considers the " concave wing of a bird " and advances an explanation of its operation, the air " being obliged to mount along the convexity of the surface, having created a slight vacuity immediately behind the point of separation." The air " accumulated thus within the cavity has to make its escape at the posterior edge of the surface, where it is directed considerably downward; and therefore has to overcome and displace a portion of the direct current

passing with its full velocity . . .," *i.e.* the air was accelerated downward beneath the wing. This was a significant observation and it would appear that Cayley understood, at least in part, the function of the curved wing as he saw it in Nature; certainly he appreciated the superiority of curved as opposed to flat surfaces because he advocated their use in mechanical flight. He may even have divined that the greatest benefit would be derived from a "slight vacuity" *above* the wing, as, in a properly cambered plane, more than half the lift is obtained, but there is no evidence in these writings.

Cayley relates how he made some experiments with a large glider (said to have an area of 300 sq. ft.) and attained "perfect steadiness, safety and steerage." "It was very beautiful," he writes, "to see this noble white *bird* sail majestically from the top of a hill to any given point of the plane below it, according to the set of its rudder, merely by its own weight, descending in an angle of about 18 degrees with the horizon." There is no testimony that this, or other gliders, actually carried a man, though there is an amusing story about a coachman who was ordered to take part in an experiment much, it is said, to his discomfort and indignation. Cayley concludes this paragraph with a plaint that his "other avocations"—and they were many—prevented him giving sufficient time to the subject of flight. He writes: "I do therefore hope, that what I have said, and have still to offer, will induce others to give their attention to this subject; and that England may not be backward in rivalling the continent in a more worthy contest than that of arms." We cannot escape the significance of this remark, even to-day.

The second part of the essay on "Aerial Navigation," which appears in *Nicholson's Journal* for February and March 1810, deals with the question of stability. Cayley stated the principles underlying it, formulated its laws and showed proof of their correctness; he indicated the method by which automatic stability might be obtained by the setting of planes with a positive dihedral angle and he showed how directional control could be effected by the use of "rudders"—vertical and horizontal. His contribution in this particular problem was probably his most valuable work.

Dealing first with lateral stability, he cites Garnerin's parachute as the worst possible form for a steady descent, due to its continued oscillation, and states that if the surface could be "applied in the inverted position," *i.e.* in the form of a flat V, the effect of oscillation would be removed because "that side, which is required to rise, has gained resistance by its new position, and that which is required to sink has lost it; so that as much power operates to restore the equilibrium in this case, as tended to destroy it in the other." This was the first proposal for the use of a positive dihedral angle to assist lateral stability in a heavier-than-air machine—an arrangement which has been, and is to-day, almost universally employed. Moreover, had Cayley's suggestion been adopted by some of the early experimenters who failed to achieve stability, the results might have been different.

He explains that "stability in the direction of the path of the machine, must be derived from a different source," and he proceeds to describe (as in the previous case with the help of diagrams) the location of the centre of pressure at acute angles, "which experiment shows to be considerably more forward than the centre of the sail [plane]," and remarks that the centre of

gravity must be below it for a condition of stability. He proceeds to describe the movement of the centre of pressure (he uses the word " resistance ") on a surface as it is presented at different angles to an air current. At very acute angles the centre of pressure is " considerably in front of " the centre of the surface, but, as the angle becomes greater, " these centres approach, and coincide when the current becomes perpendicular to the sail." " Hence," he explains, " any heel of the machine backward or forward removes the centre of support behind or before the point of suspension; and operates to restore the original position."

In order to render a machine " perfectly steady," and to enable it to ascend and descend in its flight path, Cayley declares it necessary to add a rudder " in a similar position to the tail in birds." Such a rudder he describes as " aiding the support of the weight " when considerably depressed, and a " very steady horizontal course " is thus maintained. The rudder " must be furnished with a vertical sail, and be capable of turning from side to side, in addition to its other movements, which effects the complete steerage of the vessel." In fact it is universally pivoted, and in a sketch which Cayley made in his notebook* of his first model glider (1804) the device is shown, as it is also on the silver disc, already referred to, on which he engraved crudely a design for a manually assisted glider (*see* Plate XII). There can be no doubt that Cayley originated this combination of vertical and horizontal surfaces capable of universal movement for the purpose of control—the device which has so frequently been attributed to Alphonse Pénaud, and was employed by Professor Langley and others. It is also apparent that all his findings in regard to stability were the result of his own experiments, and no apology is needed for quoting his own words, which convey that impression so convincingly.

In order to appreciate fully the theoretical work of Cayley it is necessary to study closely his famous paper and to become acquainted with the ambiguity which sometimes intrudes itself. There is little doubt that his enunciation of principles was used by others, as will be seen later, but the full value of his writings was not, until recently, appreciated, and it is probable that many arrived at his conclusions only by tedious experiment.

A survey of Cayley's work would be incomplete without a description of his first model glider (1804), which he illustrates by a rough sketch in his notebook, accompanied by data. The device consisted of " a common paper kite " with an area of 154 sq. in. fastened to a rod at an angle of 6 degrees, the rod being extended to carry a tail of the type already described, which could be set at any angle to it. The wing loading was about 3·2 oz. per sq. ft. and the speed in a normal glide about 10 m.p.h. Cayley writes that " it would skim for 20 or 30 yds. supporting its weight " and " it gave the idea that a larger instrument would be a better and safer conveyance down the Alps than ever the surefooted mule, let him meditate his track ever so intensely." These experiments, the first of their kind, were carried out near Brompton Hall in a field which slopes steeply on opposite sides.

It may be asked why there is no indication in this model, a reproduction of which is shown on Plate XII, of the use of the lateral dihedral to assist

* " Notebook (*c.* 1799-1826) of Sir George Cayley," Newcomen Society Extra Publication No. 3, 1933; reprinted *Aeronautical Journal*, June 1933.

stability; it is probable that Cayley made the discovery between 1804 and 1809. Alternatively, as this was a comparatively crude model, he may not have thought it worth while to alter the kite.* The thoroughness of his investigations here, as in other subjects, is shown by the fact that he used a whirling-arm—an apparatus for rotating models in a horizontal plane—to ascertain the lift and resistance of surfaces at different angles, the first known experiments of the kind in this connexion. He investigated the question of the power required for flight and he faced unhesitatingly the most abstruse problems; so that anyone studying his writings cannot fail to be impressed by his vision, which took him so far beyond his contemporaries in the field of aeronautics and prompted him to write: " . . . an un-interrupted navigable ocean, that comes to the threshold of every man's door, ought not to be neglected as a source of human gratification and advantage."

It is not easy to assess the whole effect of Cayley's writings, but there is no doubt that the serious nature of his work in aeronautics invested the subject with a dignity which it had previously lacked. We find the editor of the *Mechanics Magazine* referring to him as " so great an authority," and the fact that the essay in *Nicholson's Journal* (1809) was reprinted in 1895, and again in 1910, is evidence of a demand for it. That it was read abroad is certain, and we may conclude that its effect there was no less than in England.

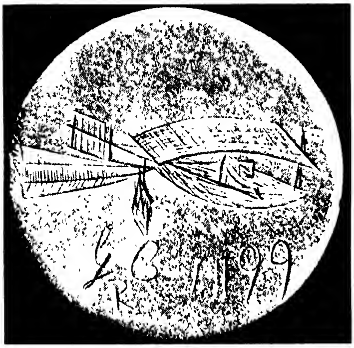
It is desirable now to consider contemporary investigation and experiment in the subject of mechanical flight—particularly that undertaken on the continent of Europe. We find that during Cayley's lifetime (1773–1857) no less than ten projects were advanced which Chanute considers worthy of description in his valuable record of early endeavour.† Of these, eight emanated from the continent and will provide some evidence of the thought there; they comprise ornithopter, helicopter and fixed plane (aeroplane) projects. Ornithopter is the name given to a flying machine whose support in flight is derived chiefly from the reaction of the air on wings to which a flapping motion is imparted by mechanical means. It is, obviously, an attempt to imitate nature in the manner described earlier in this book. Such machines, whether operated manually or by an engine, have, up to the present, always proved unsuccessful, and it is unlikely that real flight will ever be attained in that way. The use of rotating wings has, on the other hand, proved to be a successful development.

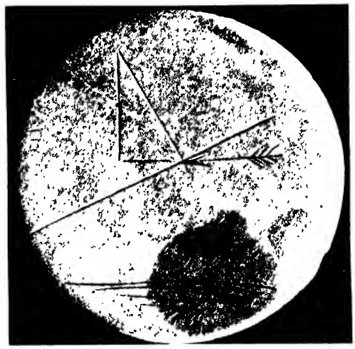
The experiments undertaken by J. Degen, a clockmaker of Vienna, between 1809 and 1812 (already referred to in connexion with Cayley) were thus not based on a sound principle, as he employed umbrella-shaped wings arranged to be flapped by the operator in order to rise. He tested this apparatus while suspended from a small balloon, so that the statement that he rose 54 ft. requires qualification and is not evidence that the machine could rise from the ground—which it certainly could not have done. Similarly, the earlier proposals of the Frenchman Gérard and Renaux, in 1784, were based on wings to which motion was to be imparted for support, but sometimes, as in the case of François Letur, support was to be derived mainly from a parachute structure with wings employed for propulsion. These projects

* For a complete description of this and other reproductions of Cayley's experimental apparatus, *see* " Handbook of the Collections Illustrating Aeronautics. I, Heavier-than-Air Aircraft," Science Museum, 2nd edition, 1935.

† Progress in Flying Machines," Octave Chanute, New York, 1894.

PLATE XII

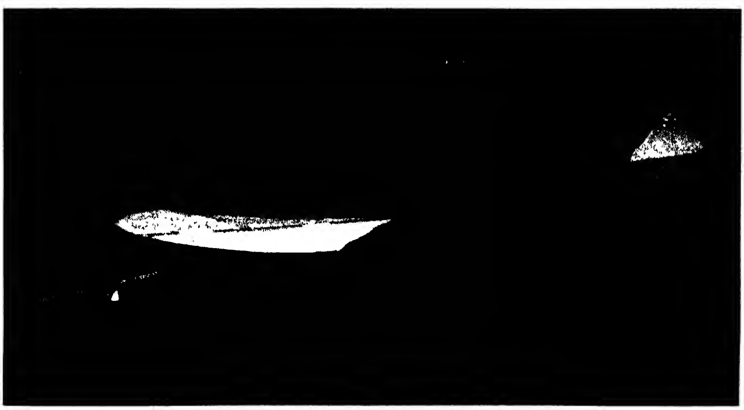




Silver Disc, one inch in diameter, engraved by Cayley 1799

Design for a manually-assisted glider — Diagram of forces acting on a bird's wing

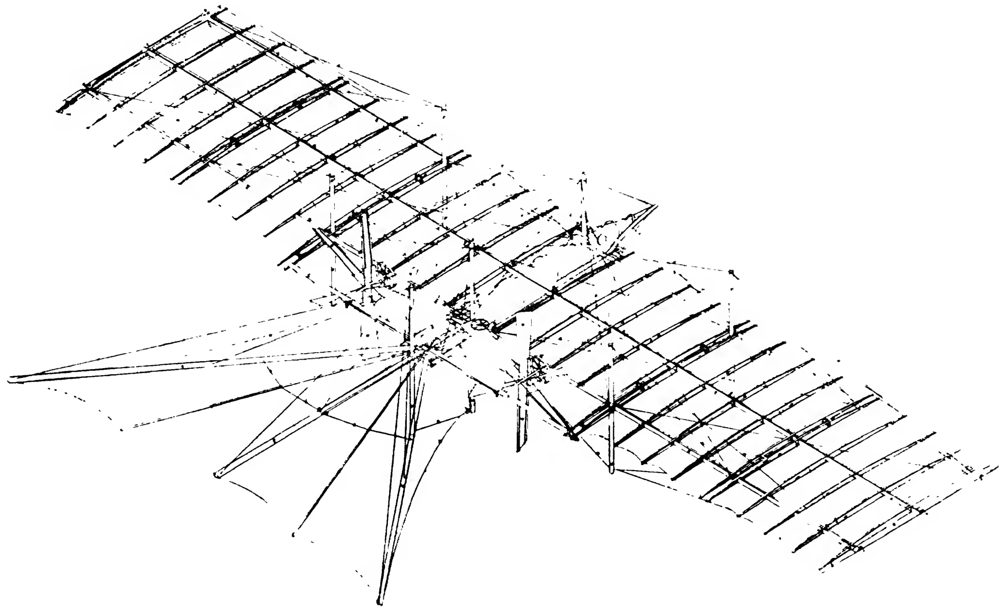
See Page 69



Cayley's First Model Glider, 1804

The earliest recorded experiment with a gliding machine. "It would skim for 20 or 30 yards supporting its weight." *See Page 71.*

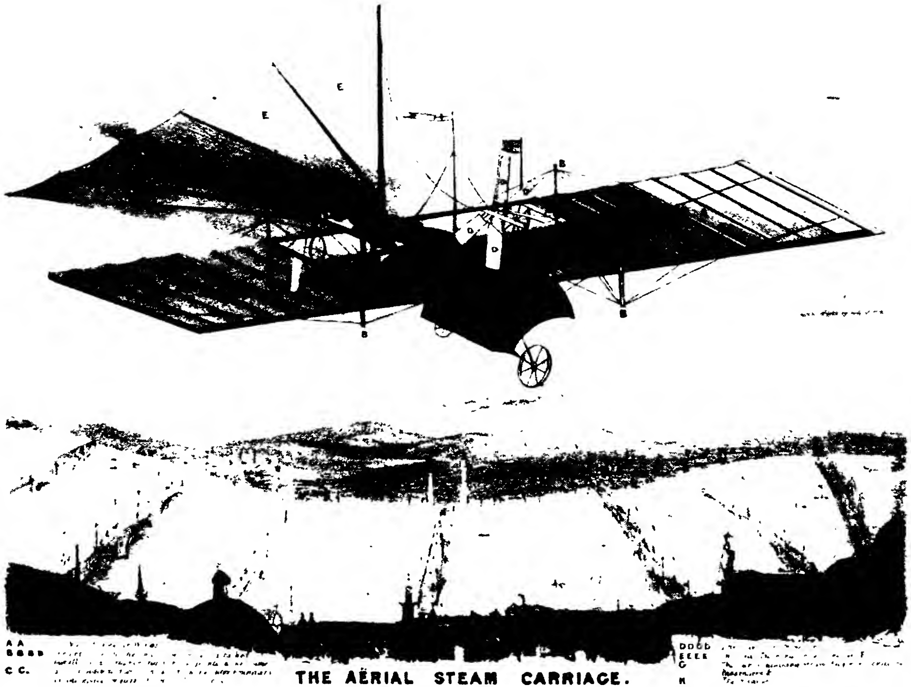
PLATE XIII



Henson's "Aerial Steam Carriage." 1842

Fig. 1, Sheet 1, accompanying the Patent Specification.

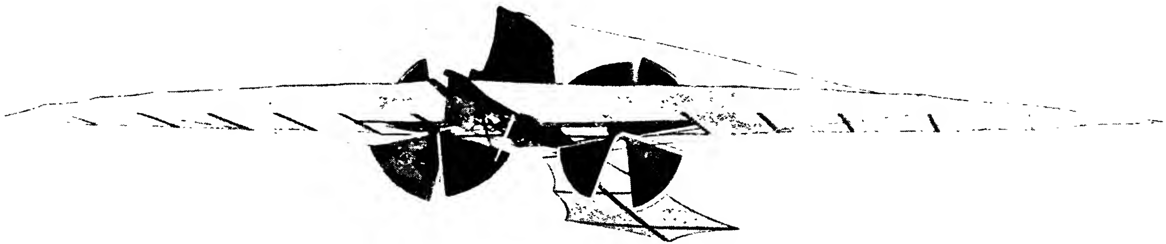
The machine which was, in all essentials save one, the counterpart of a modern aeroplane. *See Page* 75



Henson's Project in Imaginary Flight over London, 1843

Numerous prints depicted the machine flying over London, the Channel, the Pyramids and China. See Page 78.

PLATE XV



Stringfellow's Model Aeroplane 1848

The first model to fly under its own power, that of a steam engine [illegible] launching. *See Page* 70

were often tested in conjunction with balloons to which they were attached; thus Letur in 1852 ascended from the Cremorne Gardens in London, and being carried by the wind violently against some trees was fatally injured. In the case of the apparatus of Bréant (1854), the wings were provided with non-return valves to relieve the pressure on the upstroke, the downstroke to be accomplished by the joint action of arms and feet. This project, if tried, would have proved abortive. That of J. M. Le Bris (1808–1872), whose first design provided for a man sitting in a boat-shaped structure and operating wings by means of levers, is of more interest because it is stated that it was later tested as a glider—*i.e.* as a machine with fixed wings. Unfortunately the lack of some important data relating to the machine (though a patent was granted in France in 1857), and the inadequacy of the reports concerning its performance, make it difficult to assess the value of the experiments.

Some other projects were based on the helicopter principle, or on a combination of it and stationary or flapping wings. The term helicopter is applied to machines designed for vertical ascent whose support in flight is derived chiefly from the reaction of the air on one or more power-driven rotors or airscrews. No outstanding success was attained with this type of aircraft, owing chiefly to the large amount of power required and other factors, though in recent years short ascents and some control in the horizontal plane have been accomplished. It is unlikely that the helicopter will for many years be developed to the stage of practical transport. The project of Aubaud (1851) in France illustrates the combination of planes rotating on a vertical axis, fixed supporting planes and vibrating wings for propulsion in the horizontal direction. It is uncertain whether an apparatus on these lines was ever tested in any way, and, if only on account of the great power required to make it function, it could not have been successful.

Finally, there was advanced in France during the period under review one proposal for an aeroplane, or flying machine with fixed wings. This was, as far as the author can ascertain, the first proposal abroad for such a machine, and it was made in 1853, ten years after the first properly formulated design for an aeroplane patented in England—that of William Samuel Henson, a description of whose work follows. The project of Michel Loup, an artisan of Lyons, consisted of supporting planes to be propelled by four rotating wings, two on either side, in the form of primitive airscrews made of feathers. It was provided with a rudder in the form of a tail, and an elongated car fitted with wheels upon which the machine might travel when starting or alighting. The whole was based on the natural form of a bird, and its significance lay only in the fact that it provided for fixed planes and for their propulsion by rotating rather than flapping surfaces. There is, apparently, no record of any experiments having been made with it, and as Chanute remarks, "it seems difficult to conceive of its successful operation"—particularly as no motive power was indicated in detail. No attempt appears to have been made in any of these proposals to design an engine for the purpose of testing the machines, and thus an essential part of the problem of mechanical flight was left untouched. In addition, the proposals were, in all cases save one, based on wrong principles, and it will be seen that in consequence little or no progress was being made abroad during the first half of the nineteenth century. In England, however, the work of Cayley was being followed up

in a remarkable manner, and this brings us to an important period in the history of flight—the period which began with research and experiment in the application of the steam engine and terminated in the application of the internal combustion engine.

In order to understand why the idea of the aeroplane was at last formulated in a definite design and how it reached the stage of practical experiment in model scale, resulting in limited success, we must examine the conditions prevailing in England at that time. The aeroplane had been defined by Cayley in 1809, but his definition came too soon for immediate realization because the knowledge of mechanics and of engineering which it entailed were not forthcoming and, more particularly, the steam engine had not been developed to a stage which would render it a possible source of power. The first properly formulated proposal for an aeroplane can be traced indirectly to the work of James Watt in the development of the steam engine and to its subsequent influence. Owing to his efforts, the steam engine had definitely taken its place as the most important prime mover in the world with practically unlimited possibilities, and its manufacture on a sound basis provided the first training ground of a race of skilled craftsmen who helped to establish Great Britain's position as the leading industrial nation; the so-called Industrial Revolution produced engineers who were typical of that age, and when railway travel was being established, the idea that rapid transport could solve many of the problems of mankind gained strength. It is understandable in these circumstances that the idea of mechanical flight should be revived, and that the comparatively young and seemingly very ambitious engineer Henson should devote his intellect and energy to the problem.

William Samuel Henson (1805–1888) was born at Leicester, but nothing of his early life is known.* In 1820 he was living with his father at Chard in Somerset, engaged in the lace trade, and presumably acquiring that technical knowledge which later served in his—the first—aeroplane project. He certainly must have had considerable aptitude in mechanics, in addition to some technical knowledge, for his patents (in addition to that now to be considered) show ingenuity and versatility; as evidenced by No. 6,898 (1835) for lace machinery, No. 8,849 (1841) for improvements in steam engines and No. 11,797 (1847) for safety razors. He was in fact what we should call " an inventor "—a man possessing ambition coupled with a certain inventive genius, but lacking, perhaps, that solid determination and perseverance which is generally necessary for success. His work in aeronautics covered a period of only about five years, but during that time he was able to formulate the first aeroplane project in a design which was described by one qualified to judge as, " the first recorded and scientifically based attempt to connect plane surface, and weight, in relative proportion to one another. . . ."† It was also the first proposal which specified a particular engine—a steam engine—and included the design for it.

There can be little doubt that Henson was inspired by the writings of Sir George Cayley, but exactly what extent he drew upon them for his

* " Henson and Stringfellow—Their Work in Aeronautics," by M. J. B. Davy, 1931, contains a complete account of this stage in the development of mechanical flight and includes Henson's full patent specification with drawings.

† F. W. Brearey, first Secretary of the Aeronautical Society of Great Britain.

knowledge of fundamental principles must remain uncertain, because he introduced at least one feature which Cayley did not describe and he omitted another—the positive lateral dihedral; so it appears that Henson was, in certain respects, either wholly creative or had some other source of information of which we are unaware. He must have been deeply interested in the problem of flight, and it was natural that he should discuss the matter with John Stringfellow, who was also living at Chard and had similar tastes. It was said that Henson's plan to construct a flying machine resulted from a conversation between the two, but it appears that the former was wholly responsible for the design recorded in his famous patent specification of 1842, and that such assistance as Stringfellow may have given was confined to details of the steam engine.

In 1842 Henson's ambitious idea for what was later styled the " Ariel " the " Aerial Steamer " or the " Aerial Steam Carriage," materialized in the patent specification No. 9,478, for which provisional protection was granted. The complete specification with drawings was filed on March 28, 1843, under the title of " Locomotive Apparatus for Air, Land and Water," and referring in particular to " Certain Improvements in Locomotive Apparatus and Machinery for conveying Letters, Goods and Passengers from Place to Place through the Air, etc." The patent aroused a world-wide interest when, later, the newspapers of the day drew attention to the project, some by serious comment and some by ridicule. It has even been suggested that the proposal created wider interest and aroused more comment than did the advent of the first practical locomotive !

Henson's explanation of the principle has already been quoted and he proceeded to describe the machine as " an apparatus so constructed as to offer a very extended surface or plane of a light yet strong construction, which will have the same relation to the general machine which the extended wings of a bird have to the body when a bird is skimming in the air; but in place of the movement or power for onward progress being obtained by movement of the extended surface or plane, as is the case with the wings of birds, I apply suitable paddle wheels or other proper mechanical propellers worked by a steam or other sufficiently light engine. . . ." The fundamental method of the aeroplane was here laid down and Henson proceeded to describe the control in flight, which was to be accomplished by means of a tail capable of being raised or inclined for ascent and descent and a vertical rudder for steering.

Six sheets of drawings accompanied the patent specification, the enrolled drawings being coloured. Of the latter, only a few copies are known to exist and one is now preserved in the Library of the Royal Aeronautical Society. The drawing on Sheet 1 (Fig. 1) is reproduced—necessarily much reduced in size—on Plate XIII because it is essential to a proper description of Henson's project. It will be seen that the machine was to be a monoplane with the wings constructed in the manner which later became conventional *i.e.* with front and rear spars (principal longitudinal members) and connecting ribs (members which give the desired shape to the covering material of the planes and maintain that shape under load), the whole being braced by the king-post system. The trussing of the planes and body was to be arranged from central king-posts in the body structure (two in number), and an important feature of this method of bracing was that it provided what are known

as " lift " and " anti-lift " wires, *i.e.* wires which transfer the lift of the wings to the body and those which resist forces in the opposite direction to the lift. Moreover, Henson specified that the wires " be of an oval section, so as to offer as little resistance as possible in passing through the air "—possibly as a result of Cayley's suggestion—and he introduced the wire strainer and hollow spar for lightness, both of which are shown in the drawings.

The triangular tail plane, which was the elevator, was pivoted close up to the boat-shaped body structure and was capable of movement up and down to effect ascent or descent; its spread could also be reduced or increased. A vertical rudder (not shown on Plate XIII) was placed beneath the tail for steering, both controls to be operated by cables from the passenger car beneath. Six-bladed " paddle wheels " (airscrews) rotating in the rear part of the main plane, being driven by a steam engine in the car, were to provide the necessary propulsion. The steam-engine was fully illustrated in the drawings and it incorporated several features of interest—with a boiler consisting of an arrangement of conical vessels, which method of construction was intended " to obtain great strength with lightness, at the same time extensive heating surfaces . . ."—and it constituted the second part of Henson's claim. Contemporary opinion seemed to be that it was, in general, a combination of methods already employed or advanced, and this supports the main contention that Henson's work consisted in the application of existing knowledge in an extremely clever design rather than the promotion of new ideas. The power estimated for this engine was, apparently, from 25 to 30 h.p.; its weight with boiler and 20 gallons of water was calculated at 600 lb., or approximately 21.8 lb. per h.p. mean output. Henson's estimate of the power required for flight seems to accord with a suggestion made by Cayley a little later, *i.e.* that for every 1,000 lb. 8 or 10 h.p. would be necessary.*

It appears that Henson designed the aeroplane on the basis that 1 sq. ft. of supporting surface would be required to support 0.5 lb. of weight, and this again corresponded with a suggestion of Cayley's when he described a glider having a similar wing loading. Henson estimated that the total weight of his machine, with passengers, would be about 3,000 lb., so he provided for a total supporting surface of 6,000 sq. ft., of which the main planes provided 4,500 sq. ft. and the tail (which he regarded also as a supporting surface) 1,500 sq. ft. The machine would thus be very large, the main planes having a total span of 150 ft. and a chord (depth) of 30 ft. In view of these diamensions and the fact that a machine of the size would involve many difficulties in construction and be extremely costly to build (indeed the cost was prohibitive at that time and was the main reason why the machine was never constructed), one must conclude that Henson designed it on the basis of a load of so many passengers with suitable accommodation in addition to the steam engine, and that, in accordance with the given wing loading, the dimensions were determined. This is the method adopted in the light of modern knowledge, but it showed that Henson was unduly optimistic in failing, apparently, to foresee many of the factors involved in the design of a flying machine. However this may be, it does not detract from the importance of many features which he introduced; for instance, the main supporting surfaces were to be

* It is of interest to note here that the total weight loaded of the Wright brothers' first plane was nearly 1,000 lb., and they estimated that at least 9 h.p. would be required, and achieved flight with approximately 12 h.p.

double-sided, *i.e.* covered with fabric on both sides, and they were definitely curved surfaces and not flat as has sometimes been stated. The wing section proposed had a pronounced camber on its upper surface and an almost flat under-surface with the maximum ordinate of curvature at about the centre of the chord, in this respect only differing from modern practice. Even so, the wing shape was an effective one, as is shown by the fact that the " Antoinette " monoplane (1908–1910) employed a wing section which appears identical and it was, at that time, highly successful.

Henson stated his preference for "a strong close fabric," in the form of oiled silk, for the covering of all the supporting and control surfaces, and he made provision for the covering of the main planes to be drawn up when not in use to prevent damage and also, it was said, to facilitate a swift descent down an incline when starting, the covering " to be spread rapidly " at the bottom. It should be mentioned here that Henson appreciated the fact that the thrust required to enable an aeroplane to leave the ground was greater than that required to maintain it in level flight, so he proposed power sufficient only to maintain the velocity of the machine when in flight, and described how it would be launched by running forward down an inclined plane or the side of a hill in order that gravity might assist in producing the initial speed necessary for flight. Various contemporary prints illustrate this method—which, incidentally, may yet be employed in starting very heavily loaded aircraft on long-distance flights. One shows the proposed launching over the English Channel and another from an aerial station in the " Plains of Hindustan."* Therefore the undercarriage was to be provided with three wheels sprung in order to absorb minor shocks in landing, etc.† This and other features are shown in detail in the various drawings which accompany the patent specification; they are well worth studying closely by anyone interested in the technical evolution of the aeroplane.

It may be said that Henson's design embodied all the essential features of the modern aeroplane save one, and that was a positive provision for the maintenance of lateral stability. He omitted to employ the lateral dihedral advocated by Cayley or to originate any other method in the form of ailerons or other device, but relied, apparently, on a large vertical fin surface—a " sail " which was to be stretched above the main plane. This would have had an influence on lateral balance, but would probably have been insufficient to maintain it under the conditions of flight. The triangular tail, which constituted the elevators, and also the rudder surface were placed too close to the main plane to be, one imagines, very effective, though Henson mentions " the great control which the tails offer." The rudder was also of relatively small area, thus reducing its effectiveness. Both were, however, definite provisions for control in the horizontal and vertical directions and were the first applications of such devices in a properly formulated design.

A significant feature, in the light of recent knowledge, was Henson's choice of pusher airscrews in preference to tractor airscrews; the advantage derived from such an arrangement, though slight, is nevertheless, not negligible. The main features of design first formulated by Henson in 1842 were to

* Henson and his associates appear to have grasped eagerly the idea of rapid transport to India, and used it in their propaganda. Communication by steamship had already been introduced.

† Cayley had devised a light wheel for such use in 1808.

be found incorporated, in one way or another, in the majority of aeroplanes during the first years of successful flight—*i.e.* from the year 1903 onwards—and it was in those remarkable features that his contribution to development lay. He assimilated nearly all the available knowledge of his time and applied it most ingeniously in the design of the " first aeroplane project." His approach to the problem was not by way of practical full-scale experiments with gliding machines—the method by which power-driven human flight was ultimately achieved—though such experiment was clearly advocated by Cayley. He would apparently have been content to construct a machine (had funds been available) of an untried character, but provided with the power which was known to be essential. Half a century later the other school of thought prevailed, which contended that it was of little use to apply power until a machine had been evolved which could be controlled in the air by its occupant, and until evidence of its behaviour as such had been obtained.

Let us now examine the public reaction to Henson's proposal, which, as already remarked, received almost world-wide advertisement. An endeavour to exploit the invention of the " Aerial Steam Carriage " by placing it on a commercial basis was the cause of the publicity which it received. Henson, Stringfellow, Frederick Marriott, then resident at Chard, and an attorney, D. E. Colombine, became associated in this enterprise; the latter had undoubted qualities as a company promoter and publicity agent, and was obviously responsible for the legal work connected with the patent and for the issue by various printers of innumerable illustrations of the proposed machine in flight over London (*see* Plate XIV), the Channel, the coast of France, the Pyramids and China. The promotion by Colombine of the " Aerial Transit Company " and an application through Marriott to Mr. J. A. Roebuck, the Member for Bath, to procure the necessary incorporation under Act of Parliament, served to attract attention, and it was followed by the issue of a prospectus appealing for funds to secure the patent and to construct the machine. The prospectus was drafted in fulsome language appropriate to such a speculative enterprise, being extravagant, ingenious and characteristically vague. It showed, however, an appreciation of the vast possibilities of aerial travel.

On March 24, 1843, Mr. Roebuck moved in the House of Commons for leave to introduce a Bill providing for an Act of Incorporation for the " Aerial Transit Company," and it was agreed to. The reaction of members reflects the feeling of the period for a Parliamentary Report states that it was read " amidst much laughter "; it was ordered to be read a second time, but was not produced. The filing of the specification (No. 9,478) on March 28, aided by the propaganda campaign conducted by Colombine, caused a considerable stir and the newspapers published accounts in England and abroad, the particulars evidently issuing from one source. The illustrations already referred to appeared in France and Germany as well as in this country, and some found their way to America; the application for funds did not, however, meet with any adequate response.

The invention was referred to by some writers as " a very scientific conception," and *The Times* described it as being " carefully and perseveringly wrought out," the correspondent stating, with regard to the possibility of mechanical flight, that Henson " has made its eventual, perhaps early,

attainment a matter of little less than certainty." And further, that it was "high time to begin to consider in the spirit of careful inquiry and cheerful hope what will be the changes, commercial, social and political, which the possession of this new-born power will necessarily bring about."* Here indeed, was a prophet in the wilderness; but his attitude appears to have been unique, for most other criticism was destructive and mere scepticism soon turned to ridicule. Alas, consideration of the changes which the new power would bring about was indefinitely postponed, and to-day we still have far to go in our examination of the social and political repercussions.

A pamphlet entitled "The Full Particulars of the Aerial Steam Carriage which is intended to convey Passengers, Troops and Government Despatches to China and India, in a Few Days" was published at this time, and it contained most of the information which served as the basis of newspaper articles. So fantastic did the project appear to contemporary thought that the Press in general was criticized by some writers for giving countenance to such an absurd scheme and charged with "extreme ignorance of the elementary principles of science, and even of the established laws of nature." The project was described as "most visionary [which it certainly was], and fallacious," and as such it provided material for *Punch* and almost unlimited scope for the caricaturist George Cruikshank and others. It would appear that the attorney Colombine by his campaign of advertising, and Henson by his premature disclosure of the plans quite ruined all chances of serious consideration. The failure of the "Aerial Transit Company" was thus complete, and the scheme which it was to promote was utterly discredited.

The question which is, of course, paramount in connexion with Henson's project, is whether the machine would have flown had it been constructed. On account of the many factors involved this question must remain unanswered. In the author's opinion (and it can only be a matter of opinion) the power developed by the steam engine would probably have been insufficient to maintain the aeroplane in flight after launching down the inclined plane, and, had it been sufficient, it is very doubtful whether the control would have been effective to preserve stability, for which no special provision was made other than the location of weight low down in the car.

After the failure of the "Aerial Transit Company," Henson entered into an agreement with Stringfellow to co-operate in the construction of a model of the "Aerial Steam Carriage" to determine whether it could actually fly, and his more serious experimental work appears to have begun then. This was in December 1843, and it marks the beginning of a phase of experimental work on model scale which was continued by different investigators until the close of the nineteenth century. Obviously experiments on a small scale were comparatively inexpensive and, in the event of success, it was assumed that financial support would be forthcoming.

The model represented Henson's project to a scale of about 1:7 and it is now preserved in the National Aeronautical Collection at the Science Museum. The experiments with it which followed were the beginning of a valuable work which led ultimately to the accomplishment of the first power-driven model flight in 1848—an event of great importance in the history of mechanical flight. In 1847 the model was tested on Bala Down, about two

* *The Times*, March 30, 1843.

miles from Chard, and a brief record of the experiments is contained in a now rare pamphlet issued by Stringfellow's son in 1892.* It appears that they were not so favourable as was expected; the model could not support itself for any distance, and when launched "gradually descended." The thrust from the airscrews was calculated to be 5 lb. and a surface of over 70 sq. ft. was provided to support under 30 lb., but, as Stringfellow's son remarks, "necessary speed was lacking." The experiments, it is said, continued for seven weeks during the summer of 1847 and Henson and Stringfellow were forced to make some by night, being "greatly annoyed by lookers-on," and also, as it subsequently transpired, because "little puffs of wind would destroy the balance," and still air was thought to be necessary for success. Stringfellow himself describes an attempted trial at night when the silk covering of the wings was saturated by a deposit of dew so that no experiment was possible. Actually, the failure of this machine was due to three contributory causes: first the method of launching down an incline was unsuitable for a model; secondly the model was too large (it has a span of 20 ft.) for convenient handling; and thirdly its inherent stability was insufficient for sustained flight in still air and its speed inadequate to compensate for that deficiency.

It is not surprising that, in 1848, Henson in the face of repeated failure and financial loss became discouraged; he left Chard, married, and during the following year emigrated to the United States of America, where, it is recorded, he died in 1888. By his departure he lost some of the credit properly due to him for the inception of the first aeroplane project, and it was only in retrospect that his work was seen in proper perspective.

John Stringfellow (1799–1883), who continued the work, was born at Attercliffe in Sheffield on December 6, 1799. He was apprenticed to the lace trade in Nottingham at an early age and moved to Chard about the year 1820, where, as already said, he met Henson, Stringfellow inherited a characteristic mechanical aptitude from his father, William Stringfellow, and his skill earned for him a good reputation as a manufacturer of bobbins. His character seems, in contrast to that of Henson, to have been marked by a level-headedness which, coupled with energy, enthusiasm and the possession of some small resources, made him an ideal investigator in the subject of flight. In addition to these qualities Stringfellow must have possessed a sound technical sense, and in particular a knowledge of the steam engine as then evolved, because it was in the development of a light engine that he excelled.

In 1848 Stringfellow constructed a model of his own based on Henson's design, which he modified in several particulars. The model was smaller, having a span of about 10 ft. and a maximum chord of 2 ft. The planes were tapered in plan and the trailing edges were made to some extent flexible; they were braced from a central post in the body and below from the bottom of the boat-shaped car or body which contained the boiler and spirit lamp. A tail plane was fitted which could be set at different angles, but there was no rudder. Two pusher airscrews were mounted in the rear part of the main plane and were driven in opposite directions by crossed cords from a pulley on the engine shaft above the body, on which the engine itself was mounted. The general arrangement can be seen on Plate XV, which shows a true copy

* "A Few Remarks on what has been done with Screw-Propelled Aeroplane Machines from 1809 to 1892," by F. J. Stringfellow, Chard, 1892.

of the model, the original parts of which are also preserved in the Science Museum.

The small steam engine had a cylinder 0·75 in. in diameter with a stroke of 2 in. and it drove two four-bladed pusher airscrews, 16 in. in diameter, in opposite directions by means of cords running from a six-grooved pulley and giving three revolutions to the airscrews for one stroke of the engine. The total weight of the model with water and fuel was stated to be " under nine pounds " and this was supported by a total area in the wings and tail of about 18 sq. ft. As in Henson's project, the tail was reckoned as a lifting surface, but in the experiments which followed it was set at a negative angle in order to make the model rise while in flight. The loading, if the tail is included, was thus 0·5 lb. per sq. ft., *i.e.* the loading proposed by Henson. The wings were built up on two main spars and were covered on both sides with silk for about half their depth, the remaining portions, behind the rear spars, being to some extent flexible—a provision which Stringfellow made, apparently, to assist longitudinal stability and was clearly inspired by nature.

An important feature of the model was the device designed by Stringfellow for launching it. He appreciated, it seems, that the use of an inclined plane was unlikely to give success, and the essential purpose of his method was to launch the model in its correct attitude for flight. The device consisted of a carriage which travelled along a stretched wire and at a predetermined point automatically liberated the model.* He designed his aeroplane essentially for indoor experiments, knowing that the greatest part of the problem, *i.e.* that of maintaining stability, had not been solved, and that in consequence sustained flight in disturbed air was out of the question. It was his acceptance of this fact, and his ingenuity in launching, which enabled him to demonstrate—as he set out to do—that a model aeroplane could support itself in the air, by virtue of the power contained in it, under certain conditions. The achievement was no mean one, considering the knowledge of the day.

The first successful experiments were made at Chard in a disused lace factory—a room about 66 ft. long and 10 to 12 ft. high. On the second trial recorded the model rose gradually until it reached the further end of the room, where it was checked by canvas placed to stop it and prevent damage. Three local residents, whose names are recorded, witnessed this feat, and it was stated that the model climbed at the rate of 1 in 7 during flight. Four other witnesses are mentioned as having come down from London to view the experiments, including Marriott and a Mr. Ellis, then lessee of Cremorne Gardens. The distance flown must have been some 40 ft. from the point of leaving the carriage and this, coupled with the rate of climb, shows that the thrust obtained from the airscrews was quite adequate for sustained flight. The question of the authenticity of the performance may possibly arise in the reader's mind; this is very fully considered in the publication noted on p. 74, which deals with the whole work of Henson and Stringfellow, and a close examination of all the evidence there given will remove any doubts. It may be added that the genuineness of this, and a subsequent successful trial, is now accepted both in this country and abroad, though at the time the experiments were not (as far as can be ascertained) described at all in the Press and the only written record was that contained in Stringfellow's own notes, quoted by his son in 1892.

* The device is shown on Plate XVI.

As in the case of many other early experiments in aeronautics, no moral or financial support appears to have been forthcoming, and the only hope for anyone engaged in such a "wild project" was to exploit it as best they could without assistance. The pleasure ground on the banks of the Thames at Chelsea, known as Cremorne Gardens, was then at the height of its popularity and provided an opportunity for aerial experiments of all kinds, balloon ascents, parachute descents and trials of navigable balloons proving a profitable attraction. It appears that the lessee of the Gardens, who had seen Stringfellow's experiments at Chard, invited him to appear and promised to construct a covered way for experiments. Stringfellow went to Cremorne, probably early in August 1848, an announcement having been made in the Press that an exhibition of models "illustrative of the preliminary step of this new movement of the age" had been arranged. It appears that the promise of a "covered way" was unfulfilled, and Stringfellow was preparing to depart when some gentlemen unconnected with the Gardens asked to see an experiment and Stringfellow in response got up steam and started the model down the slightly inclined wire. The experiment was described by his son as follows: "When it [the model] arrived at the spot where it should leave the wire, it appeared to meet with some obstruction, and threatened to come to the ground, but it soon recovered itself, and darted off in as fair a flight as it was possible to make, to a distance of about 40 yds., where it was stopped by the canvas."

The remarkable fact about this flight was of course its duration; it was an increase of about 80 ft. over the previous flight at Chard, being made possible, presumably, by the larger space available. The prolongation of flight to a distance of 40 yds. showed that the model was sufficiently stable for operation in still air, and suggests that it could have been even further extended had there been space to do so. There is no doubt that Stringfellow's final success at Cremorne Gardens remained generally unnoticed and "having now demonstrated the practicability of making a steam engine fly," and "finding nothing but pecuniary loss and little honour," it is recorded that he gave up experiments and visited the United States of America with his son.

It was not until the foundation of the Aeronautical Society of Great Britain (now the Royal Aeronautical Society) in 1866 that he was inspired to continue his work. The inauguration of the Society under the Duke of Argyll as President marked the beginning of the systematic record of aeronautical study and achievement in England; it was an important event in the history of aeronautics and was marked by the presentation of a now classic paper on "Aerial Locomotion" by Francis Herbert Wenham—a paper which will be referred to later. It is understandable that Stringfellow should have been stimulated to further construction, particularly as it was proposed to hold an exhibition—the first aeronautical exhibition in England—at the Crystal Palace in 1868. The exhibition was opened during June of that year, and Stringfellow exhibited a light steam engine with boiler, which he rated at about 1 h.p., a working model of an "aerial steam carriage" complete with engine, and a copper boiler with furnace. He was awarded a prize of £100 for the light steam engine—the prize offered for the "lightest engine in proportion to its power, from whatever source the power may be derived." The model of an "aerial steam carriage" was even more interesting for—

largely on account of a suggestion made by Wenham—Stringfellow employed three planes instead of one, and he also adopted the rectangular form proposed by Henson, with an aspect ratio (ratio of span to chord) of about 5:1. This was the first design for an aeroplane with superposed rectangular planes, which were connected by oval section struts and cross-braced with wire; the other features were generally similar to those in the earlier models. No proper trial of the machine was possible in the Crystal Palace, and when tested outdoors it was not successful, due probably to insufficient inherent stability. Parts of it, and a reproduction, are now exhibited in the Science Museum (*see* Plate XVI). Stringfellow was then nearly seventy years of age and, with impaired sight, could undertake fine work only with the greatest difficulty. Nevertheless, he persevered almost until his death on December 13, 1883.

It may be asked what was the exact value of Henson's and Stringfellow's work in the development of the aeroplane. As the title of this chapter suggests, Henson was the first to formulate the aeroplane properly in a detailed design, the execution of which shows genius. Moreover, the publicity which his project was given, though premature, served to draw attention to a very important subject and to act as stimulant to others; the opinion that, in effect, his failure discredited endeavour in the field of mechanical flight by drawing ridicule upon it is, in the author's opinion, untenable. Stringfellow went a step further in setting out to prove that a model flying machine could support itself in the air in free flight under its own power. It was, of course, a limited achievement in that it was restricted to a small apparatus operating under artificial conditions—*i.e.* in still air—so that two fundamental problems of mechanical flight, those of controlling and guiding a machine in the air and of maintaining it in a state of stability under natural conditions, were untouched. Nevertheless, Stringfellow's contribution was profound in its significance; unfortunately his achievement was practically unknown at the time, else, one imagines, he might have had many imitators and the two problems just referred to would doubtless have been explored further. The influence of his work, as far as it is traceable, will be described in due course.

In France the experiments of two naval officers, Félix and Louis du Temple, are of outstanding interest because they mark the inception in that country of the first design for a complete aeroplane; furthermore, the former constructed a model which is credited with being the first to rise from the ground under its own power and to alight without damage.* It appears that Félix du Temple (1823–1890) was the originator of the design, which was patented in France on May 2, 1857, the specification being accompanied by drawings showing the plan, rear view and side-elevation. The drawings show some features which were present in the designs of Henson and Stringfellow, but there were notable differences and it is doubtful whether their influence can be traced at all. The machine was to be a monoplane with wings tapered (in plan) much in the manner adopted by Stringfellow, but each wing was constructed on two spars which were curved (in plan) and crossed each other, the fabric covering extending well in front of the car or body. The significant feature of these wings was that they were set with a lateral dihedral angle for stability, and this appears to have been the first application of that principle advocated by Cayley. In addition, the trailing edges were made flexible. A fan-shaped tail was shown and a vertical rudder

* "Histoire de L'Aéronautique," by Charles Dollfus and Henri Bouché, Paris, 1932.

of larger size in proportion than that of Henson, but similarly attached close to the body. A wheeled undercarriage and provision for operating the tail and rudder were also shown. The outstanding difference of the design lay in the fact that only one airscrew was proposed and this was a tractor screw, 4 metres in diameter with twelve blades, mounted at the front of the body and driven from an engine therein.

The successful model, which was based on this design, is stated to have weighed 700 grammes complete with its steam engine—clockwork was also tried—and Félix du Temple experimented at other times with a hot-air engine and a Lenoir gas engine. Precise information as to the model's performance and the conditions under which the trials took place are, it seems, not available, but the fact that it rose from the ground under its own power and alighted safely show that the power was quite adequate and that the model possessed some inherent stability, due in part to the dihedral angle. It is probable that the power for weight ratio achieved by Stringfellow in his prize steam engine and boiler of 1868—*i.e.* approximately 1 h.p., as then calculated, for 13 lb. without water and fuel—was equalled, or even improved on, to produce these results. In 1876 Félix and Louis du Temple patented a light steam boiler, which was stated to be the prototype of many which followed, and the figure of 39 to 44 lb. per h.p. quoted compares favourably with Stringfellow's 1 h.p. boiler and furnace of 1868 stated to weigh about 40 lb. They seem to have undertaken some experiments in full scale at Brest in 1874, but without any marked success.

The association of those interested in aeronautics, and more particularly mechanical flight, was made possible, as it was later in England, by the formation in 1863 of what was subsequently known as the Société Française de Navigation Aérienne. This was due largely to the enterprise of another naval officer, Gabriel de la Landelle, and Félix Tournachon (Félix Nadar). It showed that the subject had at last reached a stage which justified the exchange of opinions and the dissemination of such knowledge as was available. The foundation of the Aeronautical Society of Great Britain in 1866 has already been mentioned; it served the same purpose, and the double event consitiuted a definite stage in the evolution of the idea of flight.

The first meeting of the latter Society on June 27, 1866, was marked by the outstanding contribution from Francis Herbert Wenham (1824–1908) under the title of " Aerial Locomotion and the Laws by which Heavy Bodies impelled through the air are sustained."* It was a further contribution to the subject of form in the construction of heavier-than-air machines, but contained also an exposition of principles and an explanation of certain phenomena probably not hitherto understood. Briefly, Wenham established the fact that the useful sustaining area of an inclined plane when propelled through the air was restricted to a narrow portion of its front, and, by so doing, explained the advantage of an aspect ratio which offered a broad wing spread with little fore and aft depth. In effect, he explained the virtue of the proportions of Henson's aeroplane, which, as will be recollected, had an aspect ratio of 5:1. To make the best use of surfaces in the light of this phenomenon Wenham advocated superposed planes—a suggestion which had been made by Cayley when commenting on Henson's project in order to reduce the

* Published in the first Annual Report of the Society, 1866, but written in 1859 and later supplemented.

difficulties of construction. Thus the multi-plane form of construction originated, but Wenham went further by demonstrating that it was unnecessary to reduce the wing loading to the extreme limit which had previously been deemed necessary. In this connexion he endorsed Cayley's opinion in the words: "... the whole secret and success in flight depends on a proper concave form of the supporting surface." These and many other conclusions were, it seems, derived from his own observation of natural flight and experiments, and were based on the soundest reasoning. In 1871 he undertook, with John Browning, what were probably the first experiments ever made with a wind tunnel—experiments initiated by the Aeronautical Society.*

The Aeronautical Exhibition held at the Crystal Palace in 1868 provides fair evidence of the experimental work being done at that time. Of the model heavier-than-air machines exhibited, two appear to have been helicopters, two aeroplanes and the remainder ornithopters. There seems no evidence that any of the machines flew at the time of the exhibition (Stringfellow did not show his model of 1848) or on any other occasion, except the model helicopter made by the Viscomte Ponton D'Amecourt which was credited with having risen successfully, but was not tested at the Crystal Palace. Apart from Stringfellow's model triplane, the only machine with fixed surfaces appears to have been that of J. M. Kaufmann which was furnished with additional flapping surfaces for propulsion. Fifteen examples of light engines, of which eight were steam engines, were shown. Two were designed to use guncotton as a motive power and five were definitely gas or oil engines, but none of the latter were shown in motion and in some cases their action was not even explained.

The steam engine remained the only source of power, and though Stringfellow and Felix du Temple had obtained remarkable results on a very small scale, the possibility of its successful application in a man-carrying machine was remote. When it is recollected that Henri Giffard's dirigible of 1852 was propelled by a steam engine which developed about 3 h.p. for a weight of 350 lb. complete with boiler, it will be appreciated that there was little likelihood of such a power unit being lightened sufficiently for human flight, but it is doubtful whether this was realized, because at that period there was no agreed estimate of the power required for flight, *e.g.* in the case of Henson's project estimates of 4,510, 701, 247, 114, 100, 60 and 3 h.p. were advanced by various individuals!

The lack of a suitable power unit probably saved several lives, for it restricted experiments to model scale and it ensured, as will be seen later that the principles of control were investigated before attempts were made to fly under power; thus the aeroplane evolved in accordance with the sequence of definition, formulation in a design, practical test to determine behaviour in the air and, finally, the installation of power. The question of behaviour in the air was the most abstruse. Obviously a flying machine should be to a large extent inherently stable; the analogy of bird flight was in this respect unsatisfactory, because the bird has instinct with life and meets any emergency instantly, whereas the machine, being inanimate, should possess some power to correct automatically instability which may arise.

Returning to the development of the aeroplane in France we find, nineteen years after the original design of Félix du Temple, the emergence of

* See Aeronautical Society's Report for 1871 and 1872.

another which was in many respects remarkable. This was the design of Alphonse Pénaud (1850–1880), who may be regarded as the enlightened pioneer of the aeroplane in that country. He began experiments with a helicopter, but abandoned them in favour of the fixed plane and he constructed a small model which made well-sustained flights before the Société de Navigation Aérienne on August 18, 1871. In 1876 he patented his design (executed in 1873), which will ever be famous by reason of the fact that it incorporated features which anticipated the practice of forty or fifty years later. This was undertaken in collaboration with an engineer-mechanic, Paul Gauchot, and the drawings show the machine to be a monoplane designed as an amphibian, *i.e.* it was intended for operation from land or water and for this purpose the landing-wheels were made retractable—an arrangement not generally adopted until more than half a century later.

It is impossible to do justice to Pénaud's project in a brief review; during the short period of his working life he assimilated all the knowledge his predecessors had possessed and his genius enabled him to apply it and, at the same time, acquire further knowledge. Perhaps his outstanding achievement was his demonstration of the now conventional method of maintaining longitudinal stability by the use of a tail plane placed far behind the main planes. This was effected in his model (which was driven by twisted rubber) by placing two small horizontal surfaces at some distance in rear of the main plane " at an angle of about 8 degrees pointing below the horizon of the main aeroplane " so that with the centre of gravity located a little in front of the centre of pressure of the main plane, longitudinal stability was automatically maintained. He proved the correcting influence of such stabilizing surfaces set at an appropriate distance from the main surface in the manner indicated by Cayley in his model glider of 1804. In the final design these take the form of an upturned trailing edge of the main plane and twin elevators are attached thereto, and, very remarkably, Pénaud conceived the idea of connecting them and the vertical rudder to a single lever for convenience of operation, and his proposal is generally regarded as the origin of the modern control column—colloquially termed "joystick." The wings were set at a slight dihedral angle for lateral stability, and in addition the tips were slightly upturned. In plan, the wings have roughly the form of an ellipse extending over nearly the whole of the body, and if any criticism may be offered it is that the aspect ratio was too small for efficiency and the wing section not a very good one. The twin elevator planes have sometimes been regarded as the inception of the modern aileron control, but it is not the case as, from their location, they would, even if operated in opposite directions, not fulfil the purpose of ailerons, *i.e.* impart a rolling motion to the aeroplane. Pénaud appears to have specified an angle of incidence for the main planes of 2 degrees and the wing loading was about 4 lb. per sq. ft., a much greater loading than any previously contemplated. The total weight estimated with two passengers was 2,640 lb. and the power required to fly at 60 m.p.h., 20 to 30 h.p.; the latter was a fairly accurate forecast of what was to be achieved by light aeroplanes some fifty years later.

It seems that a steam engine was contemplated, but its design was, apparently, not specified, though two four-bladed tractor airscrews were shown. The car or body was to be boat-shaped for alighting on water in accordance

with the idea of an amphibian. The machine was never constructed owing to lack of funds, and the problem of sufficient power within the weight limitation would at that time have been insuperable. Had it not been so and the work completed, it is probable that the machine would have flown—but this must, of course, be largely a matter of opinion. Pénaud will be remembered best for his investigation of the problem of longitudinal equilibrium; unfortunately his work was unrealized and unrewarded, and in 1880 he committed suicide.

A contemporary and rival, Victor Tatin (1843–1913), experimented with a *Oiseau méchanique* in 1875, and four years later with a compressed air driven model aeroplane, which is preserved in the Musée de l'Aéronautique. The latter is a monoplane with a fan-shaped tail reminiscent of Henson's design, but it is driven by two four-bladed tractor airscrews. A large cylindrical container for the compressed air forms the body of the aeroplane, which is mounted on four wheels of relatively large size. It cannot be said that Tatin's design shows any marked advance on earlier work, but his method of trial is interesting. The model was attached by cord to a central stake, and in that manner accomplished several tethered flights; obviously the method had limitations, but it served to demonstrate the lift obtained. Tatin subsequently collaborated in the design of the early Santos-Dumont dirigibles.

In 1877 the Austrian engineer Wilhelm Kress (1846–1913) began experiments with elastic-driven model aeroplanes, several of which are exhibited in the Technical Museum at Vienna. A characteristic of these models—which accomplished short flights, rising from the ground—is the swept-back wing and the largely flexible extremities of the wings. Clearly the design is based closely on natural forms, apparent in the shape of the wings and even the airscrew blades. For this reason it is difficult to imagine this, and other similar contemporary designs, forming the basis of any full-scale machine, as the difficulties in construction would have been insuperable. Kress, however, constructed a large aeroplane mounted on floats in 1901, but it was unsuccessful. He represented a school of thought which adhered too closely, it would appear, to the imitation of nature, and, as in other cases, fine talents were dissipated in the imitation of such forms.

In Italy the experiments of Enrico Forlanini (1848–1930) were concerned more with the helicopter principle than with the aeroplane, but they are of interest because of his success with the former and as evidence of the modern investigation of mechanical flight in that country. Apparently experimental work on a scientific basis started later in Italy than in other European countries. The revival of learning which began there early in the fifteenth century and the classical work of Leonardo da Vinci and Borelli in regard to flight had no counterpart in the investigations of the nineteenth century, and it is not until quite recently that we find development of the highest standard. Professor R. Giacomelli has distinguished the development by three periods: the first from the fifteenth to the eighteenth century, when the physical possibility of human flight on the two principles was conceived and the conditions of natural flight explained; the second the period of experiment with balloons; and the third that of scientific investigation, of which Forlanini may be regarded as the pioneer. His achievement was primarily the construction in 1877 of a steam engine driven helicopter model which ascended, it is said, 40 ft. from the ground. The model consisted of two double-bladed airscrews, the lower being attached to the steam engine and framework and the upper free to rotate

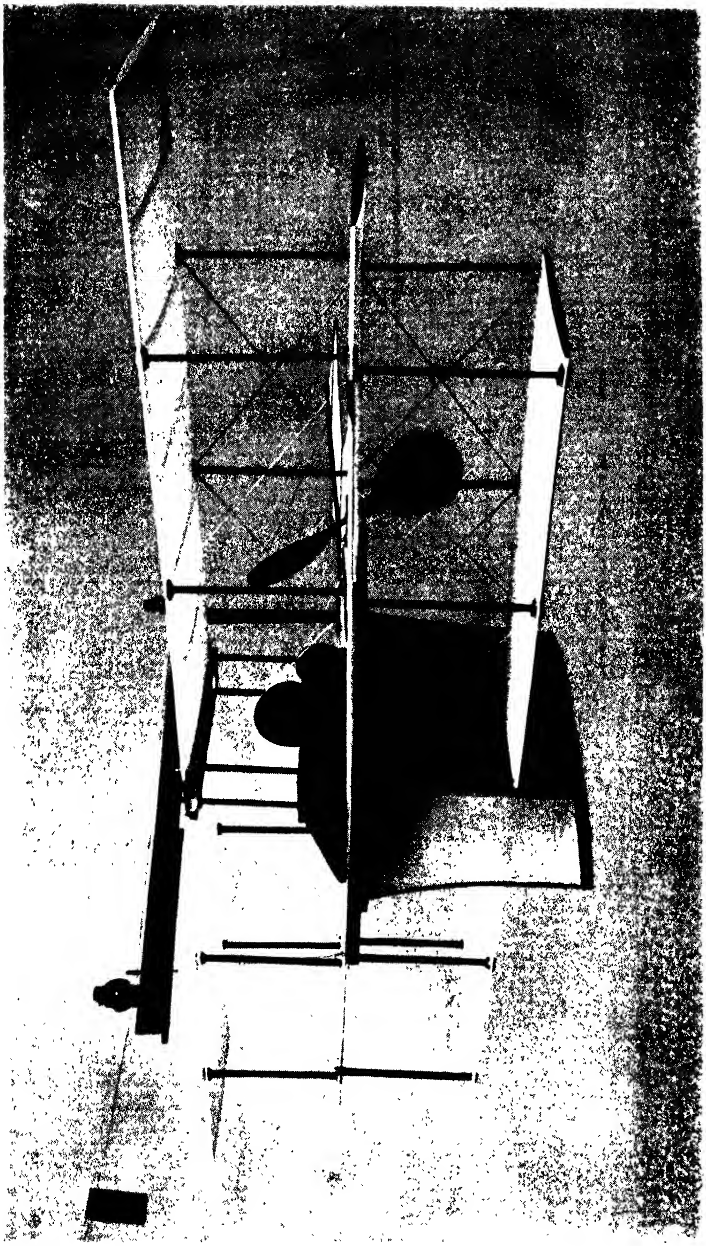
and driven by the engine, estimated at 0·25 h.p., through bevel gearing. When in operation, the whole apparatus rotated slowly in the air. No fire or boiler was carried, steam being supplied from a reservoir at an initial pressure of 120 to 160 lb. per sq. in. The fact that steam was not generated in the model itself, but prior to its ascent, made the performance possible by the reduction in weight thereby effected. An earlier proposal for a boiler fired by alcohol jets was, it seems, abandoned as being too heavy. In 1885 Forlanini made a model aeroplane to be propelled by the reaction of gunpowder exploded in a tube, but apparently without notable success. As in the case of several other experimenters, he turned to airship construction and his work in that connexion has already been referred to.

Contemporary with the experiments in France, Austria and Italy already described (there seems to have been little investigation in Germany during this period), Thomas Moy was testing a model steam-propelled aeroplane in England. In collaboration with R. E. Shill he patented a design in 1871 (No. 3,238), and in 1875 the large model, known as "Moy's Aerial Steamer," was tested in tethered flight at the Crystal Palace. The interest attached to the project appears to have centred round the claim that the light steam engine could be reduced in weight to as little as 7 lb. per h.p. Actually, in the model the engine weighed 80 lb. and developed about 3 h.p., the total weight being 120 lb. When tested as described it was said to have risen a few inches from the ground, but the experiments cannot be said to have resulted in any addition to knowledge, and a great deal of money was spent in this and other projects. It was scarcely to be expected that the method of tethered flight would lead to any valuable results, though it served to determine, to a certain extent, the ability of a machine to support itself.

The last twenty-five years of the nineteenth century witnessed considerable activity—and competition—on the part of several engineers to construct a practical flying machine. Thus, in England Sir Hiram Maxim—who had won distinction in other problems—and Horatio Phillips turned their attention to the subject. In France Clément Ader constructed several full-scale flying machines and, in the United States of America, Professor Samuel Pierpont Langley, a distinguished man of science, entered upon elaborate research. The work of Lawrence Hargrave of Sydney, New South Wales, also began during this period. In no case were their efforts rewarded by success and this was due to the fact that two fundamental problems remained practically unsolved. The first was that no engine sufficiently light for use in an aeroplane had been evolved, and the second that the control of a heavier-than-air machine in the air by its occupant had not been explored. Success could not be achieved without solving both these problems and combining the solutions in a practical machine. It is proposed now to describe the final experiments which preceded the short period of actual experiment in the air—gliding flight—which led to the achievement of control and a knowledge of the air. It will be seen that some of these overlap the gliding experiments, but the latter constitute quite a distinct phase in development which calls for separate description, so the slight departure from strict chronological order is justified.

The experimental work of Sir Hiram Maxim (1840–1916) is fully described in his book "Artificial and Natural Flight." He states that his attention was directed to the subject as early as 1856 by a proposal of his

PLATE XVI



Stringfellow's Triplane, 1868

The first design for an aeroplane with rectangular, superposed planes; the model is shown in position on the automatic launching carriage See Page 83

PLATE XVII

Lilienthal in Gliding Flight, 1893

He created the art of motorless flight which preceded and was essential to the achievement of mechanical flight. (See Page 102)

father's for a helicopter with two airscrews on the same axis to be rotated in opposite directions, and that in 1872 he began drawings for such a machine. The helicopter in a simple form appears to have given the initial inspiration to many investigators. The device of Launoy and Bienvenu (1784) has already been described and Cayley experimented with a similar apparatus. It is said that the Wright brothers' interest was first aroused by a toy helicopter (probably of the same type) which their father had given them. Obviously the helicopter in its primitive form had an important influence on the investigation of flight in so far as it was a phenomenon outside ordinary experience, and served as a basis for speculation. Maxim, however, soon abandoned the idea as no engine could be made sufficiently light, and about 1889 he began to conduct a series of experiments to determine the relative efficiency of model aerofoils and airscrews by the use of a rotating arm—the method previously employed by Cayley. Having done a considerable amount of research in that manner he began about 1891 to construct a large aeroplane to obtain further data and to test the efficiency of his compound steam engines specially evolved for the purpose of flight.

The aeroplane had a central plane, of strange shape, 50 ft. wide and two small planes 27 ft. in length attached to it on either side at dihedral angles, and two others placed beneath them. Fore and aft elevator planes were fitted, bringing the total area up to 4,000 sq. ft. The two steam engines were designed to produce about 180 h.p. each at a steam pressure of 320 lb. per sq. in., and drove two large airscrews on either side. The total weight with 600 lb. of water, fuel and three passengers was about 8,000 lb., *i.e.* a loading of 2 lb. per sq. ft. of surface. All this was undertaken, it seems, merely to obtain data in full-scale experiment, without attempting free flight. Thus, under test the machine was not allowed to rise more than about 2 ft. above the steel rails on which it ran being restrained by wheels engaging in a safety track of timber placed above. On the first trial in 1894 none of the wheels left the rails, but on a third test with steam at 320 lb. per sq. in. the machine was lifted clear of the rails on which it travelled, showing that it was for a time wholly supported in the air. The test ended, however, in disaster owing to the breakage of a rear axle resulting in partial wreckage of the machine. Maxim calculated that the total lift was not less than 10,000 lb. and the net result of his experiment was that the lift exceeded the weight of the machine so that, without the restriction of the overhead rails, the machine should have been able to fly. It is, however, extremely improbable that it could have been controlled in the air sufficiently to prevent an immediate disaster. Maxim apparently made no full-scale test of the efficacy of the controls provided, in order to determine that the machine would be stable in the air, and the value of his work in regard to mechanical flight seems to lie mainly in his demonstration that the steam engine complete with boiler, etc., could be lightened to weigh from 8 to 9 lb. per h.p. without fuel and water. His research was extensive and his experiments elaborate, but they were, unfortunately, not followed up by an investigation into the problems of stability and control in the air. He, in common with many other inventors, seems to have considered the aeroplane as an invention very valuable in war, and its significance as such appears to have overshadowed any other use, so that from its inception it was regarded as a potential instrument for military purposes rather than the most remarkable vehicle for transport which man has evolved.

The experiments of Horatio F. Phillips (1845–1912) were of much more significance because they were directed to the investigation of the efficiency of curved planes—a subject of very great importance. In 1884 and 1890 Phillips, after many years of study and experiment, patented (Nos. 13,768 and 20,435) a form of wing section known as the " Phillips entry." Its chief characteristic was a thick and somewhat dipping leading edge which reduced drag, but in these patents a whole series of curved shapes were shown under the general title of " blades for deflecting air." He seems to have realized at the outset that the best shape for an aeroplane wing was one which would, when in contact with an airstream, deflect the current upwards and thereby cause a partial vacuum just above the upper surface, resulting in an increased lift. His conclusion, arrived at after about twenty years' research, during which he used a form of wind tunnel, was a very valuable contribution to the science of mechanical flight, and his wing section was the forerunner of the modern aerofoil. His demonstration—for it must be regarded as such—that, by a proper use of curved shapes, the pressure on the lower surface of an aerofoil could be combined with suction on the upper surface to produce a very considerable reaction, was a profound achievement. Actually the air-pressure beneath the plane may only provide about two-fifths of the total lift, the remaining three-fifths being supplied by the suction above it. The significance of Phillips' research is thus apparent, and he constructed a machine to test the efficacy of the wing shape he proposed. It consisted of fifty planes 19 ft. long and 1·5 in. wide placed one above the other at a distance of 2 in. apart in the manner of a Venetian blind, the total supporting area thus obtained being 136 sq. ft. The whole was attached to an undercarriage fitted with three wheels and designed to travel on a circular track of wood. The motive power was a steam engine driving a single airscrew. No provision was made for a passenger, but the machine carried a dead weight of 72 lb., the total weight being 385 lb., so that the loading was nearly 3 lb. per sq. ft. of supporting surface. In 1893 the machine was tested at Harrow, when it is said, the two rear wheels, which carried most of the weight, rose 2 or 3 ft. from the track for a distance of 150 to 250 ft., the speed being about 40 m.p.h. A subsequent test was made on a larger track and it was claimed that the steam engine was able to lift 72 lb. per h.p. developed; this was a remarkable result and appeared to confirm all Phillips' theories regarding the efficacy of his wing shapes.

About ten years later he constructed another machine, and under test it was found to be unstable, but a third, it is said, succeeded in leaving the ground for an appreciable distance. Phillips' best work was his thorough investigation in connexion with the curved plane and his contributions in regard to it, and he deserves a high place among the pioneers of mechanical flight. It may be asked why it took him twenty-five years to evolve a shape which is to be found in the wings of soaring birds such as the Albatross and the Gannet. The explanation is probably twofold: if Phillips had observed nature, he would, as a man of scientific mind, have wanted to discover how the best wing shapes functioned and his method of determining air-pressures by means of artificial currents would have told him. Also, he may have observed nature without conviction that the forms, as in the case of the best soaring birds, were evolved in accordance with their requirements, as Darwin's theory showed.

The experiments of Clément Ader (1841–1925) in France, on the other hand, were concerned with the application of power rather than with

aerodynamic theory or investigation into the problem of stability and control; though the word " Avion " which he created has survived as a generic term for heavier-than-air aircraft. His work has probably led to more confusion in its interpretation than that of any other pioneer, including even Langley and the Wright brothers, because of extravagant claims made concerning it and the lack of corroborative evidence. Ader was born at Muret in 1841 and went to Paris to exploit his talent as an engineer, where about 1880, he was engaged in the perfection of the telephone and its installation. The problem of flight had always interested him, and about 1872 he began to make an ornithopter which he exhibited but soon abandoned in favour of machines with fixed wings. His study of nature appears to have been extensive, taking him to Northern Africa, but strangely enough he selected a flapping-wing mammal—the bat—and not a soaring bird as the basis for his formulation of the aeroplane. His first steam-driven, man-carrying machine was completed secretly in 1889 and patented on April 19, 1890; it was named " Eole," had wings shaped like those of a bat and was fitted with a steam engine of 20 h.p. driving a single, four-bladed tractor airscrew. The wings were articulated and capable of various movements stated to be sufficient for all manœuvres in the air; in practice the control would be effected by an appropriate distortion of what was virtually one continuous surface—including the tail. The patent shows an enclosed body, which contained the operator and the steam engine, with a condenser mounted vertically above it; the whole was mounted on wheels for running over the ground. Wings, which had a span of about 46 ft., could be folded; the total weight was about 1,000 lb.

The machine was tested at Armainvilliers on October 9, 1890, and it is claimed that it was the first occasion in history on which a man had left the ground in a heavier-than-air machine solely as the result of an engine contained in it. It is not suggested that this constituted mechanical flight, as we understand it, because the performance was not sustained, or repeated, so that there is no evidence that it could have continued sufficiently long in the air to show that it was under control. The most credible evidence of the performance is contained in a document recently published for the first time * which is a verbal testimony of certain witnesses, but was not signed. This document states that the machine left the ground for a distance of 50 metres; it also mentions that the surface had been rolled and was 200 metres long and 25 metres wide, so it appears that the performance was not restricted by the size of the ground, and this is confirmed by a statement that unfortunately the stability of the apparatus was insufficient to allow the experiment to be continued without temerity, which apparently Ader was not prepared to do. The " Eole " was, it seems, reconstructed and modified and it is clear that the experimental work attracted attention and gained some approval from the military authorities, because in 1891 he was given permission to move his machine to the military ground at Satory in order to make a further trial. On this occasion also it was claimed that a " flight " was made, but the evidence is inconclusive, and as the machine was wrecked further attempts could not be made.

It seems quite clear that the machine lacked the stability and adequate control necessary for sustained flight; nevertheless the French Ministry of War was sufficiently impressed to grant certain funds for experiments. Ader's next machine, constructed in 1892, was named the " Avion " and proved

* In the " Histoire de l'Aéronautique," Dollfus and Bouché, 1932.

unsuccessful; another, "Avion III," completed in 1897, was fitted with two steam engines of 20 h.p. each driving two four-bladed airscrews. The trials with this machine took place at Satory on October 12 and 14, 1897, before Generals Mensier and Grillon and others delegated to report to the Ministry of War on the result. On the first occasion the official observers found that the imprint of the wheels when running on the indicated track was not consistent, and in some places scarcely apparent, showing that the machine had been partially air-borne; Ader, however, maintained that he covered the track by a series of small flights during which none of the wheels touched the ground. On the second occasion according to Ader,* a strong wind got up and he experienced difficulty in keeping the machine within the indicated area; it descended abruptly and was partially wrecked. The official report,† minute in its detail, apparently credited the "Avion III" with making several hops, but whether these were due to the inequalities of the ground, to the strength of a following wind, or to lift exerted by the machine itself remains in doubt. It would appear that the observers themselves were not wholly in agreement and Ader's version of what occurred was quite different. The official view seems to have been that, though the machine had not flown, it was "capable of flight," but the authorities decided not to finance further experiments and the "Avion III" found its way into the Conservatoire des Arts et Métiers, where it is now preserved. Ader, discouraged after forty years of labour, abandoned experiments, but only after seeking in vain for private support. His failure was accentuated by the fact that he did not apply the knowledge already available concerning the form an aeroplane should take; his machine was based too closely on nature and the supporting surfaces appear to have been crude and inefficient. Had he, for instance, applied Henson's wing shape the lift obtained might have been sufficient to raise the machine, but a sustained flight would have been unlikely.

The kite, which had so long been neglected, was investigated and developed by Lawrence Hargrave (1850–1915), who is known chiefly by his pioneer work in that connexion though his researches were extended to almost every aspect of mechanical flight. His experimental work with models was begun in 1884, and in that year he read a paper entitled "The Trochoided Plane" before the Royal Society of New South Wales. The paper dealt with the movements of animals and fishes, and led up to the study of the flight of birds. A second paper, read in 1885, dealt with experiments with various models, and he contributed no less than nineteen papers to the Society during the period 1884–1909. He experimented with nearly fifty models, provided generally with clockwork or twisted rubber as motive power, propulsion being effected by flapping wings and also by airscrew. In 1885 a flight of 120 ft. was achieved with one of these wing-propelled models. About 1887 Hargrave turned to the development of various types of model engines, and he is credited with the invention of the rotary type, *i.e.* that in which the cylinders revolve about a stationary crankshaft. This model engine was driven by compressed air, as were most of Hargrave's engines; he experimented, however, with petroleum vapour and steam as sources of power. His experiments with aeroplane models continued until 1893, but it may be said that, apart from the conception of the rotary engine, he discovered little that was not already known.

* "L'Aviation Militaire," Paris, 1910.
† Dated Paris, October 21, 1897.

In 1893 he began his work on kites, for which, as already remarked, he is chiefly famous. It has frequently been stated that he invented the box-kite—*i.e.* that in which cellules are employed instead of single surfaces—but in view of a patent of 1871 (Danjard) and the "aero-bi-plane" exhibited in London in 1874, the conception of superposed surfaces arranged as units one behind the other on a horizontal member was not a novel one. However that may be, Hargrave developed the cellular system on a scientific basis and evolved forms of kites which were definitely superior to any contemporary examples—and in this connexion it must be remembered that he was working independently at a great distance from others similarly employed. Of the many different types of cellular kites which Hargrave evolved, one was found to be markedly superior. It consisted of two cellules mounted one behind the other on a horizontal rod, all the four horizontal lifting surfaces being evenly curved with the convex sides above. The pull exerted by this kite was found to be double that of one of similar dimensions but with flat surfaces, and Hargrave's subsequent experiments were directed to perfecting this type. He developed the box-kite to produce more lift with greater stability and less drag than had previously been obtained, and he demonstrated that a relatively small surface arranged in kite form was sufficient to lift the weight of a man. He conceived also the idea of an adjustable tail to be used in connexion with his kites, and it may be said that he laid the foundation for the type of aeroplane cellular structure later adopted, as exemplified in the early Santos-Dumont and Voisin machines; it was not, however, a form which long endured.

The final type of kite evolved (1909) had the horizontal surfaces curved so that the front half of each was slightly convex and the rear half correspondingly concave; it represented the sum of Hargrave's research in the application of the curved aerofoil to kite construction and was superior to all the others. The results of his research may have been more far-reaching than is at first apparent, by reason of the fact that they were made public in the various papers already referred to. Many of his early flying models are preserved in the Deutsches Museum at Munich and in the Technological Museum,* Sydney, while three of his original box-kite models are in the Science Museum.

The work of Professor Samuel Pierpont Langley (1834–1906) constitutes the last phase in that activity which is classified here as the definition and formulation of mechanical flight, because, though it was at first theoretical and mathematical, then experimental on model scale and finally experimental on full scale with a man-carrying machine, it did not include actual practice in the air, which alone could have carried it a stage further. In the whole history of aeronautics there appears to be no man more deserving of success than Langley in view of his great efforts, yet he met with more disappointment than was accorded to many and his failure was tragic in its effects.

Langley became interested in aeronautics late in life; he had already had a distinguished career as a man of science, being Assistant Professor of Mathematics at the United States Naval Academy, Professor of Physics and Astronomy at the Western University of Pennsylvania and later Secretary of the Smithsonian Institution at Washington. A complete account of his investigations in aeronautics is contained in the "Langley Memoir on Mechanical Flight," published by the Smithsonian Institution, and it appears

* *See* "The Aeronautical Work of Lawrence Hargrave," 1933, by T. C. Roughley, B.Sc., Technological Museum, Sydney, Bulletin No. 19.

that he began his actual experimental work there in 1889—work which resulted in the publication in 1891 of his "Experiments in Aerodynamics," a scientific treatise the purpose of which was to prove mathematically that it was possible to propel and sustain a heavier-than-air machine in the air. During the same year he began the construction of his first power-driven model aeroplane—which machine, and subsequent ones, he named "aerodromes," or, literally, "air-runners." It is interesting to note that Langley approached the problem by way of nature, having tested the reactions of various birds' wings on a whirling table, but he abandoned this method in favour of the study of the successful models already constructed, and in this connexion he examined, it is said, Pénaud's designs, and it is known that he acquired Stringfellow's prize engine sometime after the exhibition of 1868. The internal combustion engine was still (1891) insufficiently developed, and he employed various types of model steam engines before adopting that which he considered most satisfactory. He proposed also to provide an apparatus to steer automatically in order to prolong the duration of flights.

In 1896 two model "aerodromes" were tried and one proved to be remarkably successful, flying three complete circles and covering, it is said, a distance of 3,200 ft., which was later increased to 4,200 ft., the speed being about 25 m.p.h. These were, of course, by far the best performances yet recorded, and the fact that they were repeated and were made in the open air under natural conditions gave promise of ultimate success. The form of construction adopted was that of two sets of monoplanes, with pronounced dihedral angles, arranged in tandem fashion on an elongated framework of steel, the engine being situated between the two sets of planes and driving two airscrews, one on either side. A form of adjustable tail was used, consisting of two surfaces placed at right-angles to one another; an additional rudder was generally placed between the two sets of planes. The difficulty of launching at the correct angle was finally overcome by the use of a special apparatus; as in the case of Stringfellow, it was found to be by no means the least part of the problem.

The characteristics of this last, and most successful, model were curved planes set at dihedral angles sufficient to ensure adequate lateral stability—the method proposed by Cayley nearly ninety years earlier had at last been vindicated—and a tail arrangement which served to correct to some extent loss of longitudinal balance and to maintain the model in horizontal flight. The power (stated to be from 1 to 1·5 h.p.) was obviously sufficient for sustained flight when the difficulty of launching had been overcome. The model, which had an overall length of about 16 ft. and a span of 12 to 14 ft., was said to weigh 25 lb., and it would appear that the structure was sufficiently strong to withstand ordinary tests, though the evidence on this point is not very full. It was reasonable to suppose that a large machine on similar lines—taking into consideration the factor of scale effects—might also be successful, and it appears that Langley had confidence that it would, though his ambition was then (1896) hampered by lack of funds and to a certain extent, it is said, by public ridicule.

There were three factors upon which the success of a man-carrying machine, based on the models, depended. The first was the development of

a sufficiently light and powerful motor, as the steam engine was unsuitable for full-scale experiments; the second an efficient method of starting the machine on a flight; and the third adequate control and stability while in the air. It will be seen later that Langley met the first problem by having a petrol engine specially constructed, and that he devised a method of launching which he considered satisfactory at the time. He did not, however, attempt to test by any full-scale experiments the system of control he provided, and it will for ever remain in doubt—in spite of all that happened subsequently—whether that control would have been adequate for sustained flight. The only way to test the adequacy of a control was to experiment with it in the air, and to do this it was necessary to adopt the method of gliding flight with a motorless machine. It will be seen that this was essential to the proper development of a man-carrying aeroplane and it forms the subject of the next chapter.

In 1898 Langley was requested by the President of the United States, through the War Department, to undertake the construction of a man-carrying "aerodrome." The request, it has been said, was stimulated by the declaration of war against Spain by the United States and, if so, it shows that, from the very beginning of practical development, the aeroplane was regarded primarily as an instrument of war, and the fact that Langley had previously been unable to obtain support for its development is further evidence of this attitude. Consideration of Langley's subsequent work, which ended in 1903, will be deferred to a later chapter; in the meanwhile the era of practical experiment in the air, leading to the accomplishment of mechanical flight, had begun.

The period of nearly one hundred years during which mechanical flight was defined and formulated has been reviewed here in some detail because it is felt that the history of the initial development of the aeroplane deserves fuller consideration than it has hitherto received. There is a natural tendency, when recording the facts of a new movement or the development of a new idea, to concentrate on its realization and to examine less closely the evolutionary period which preceded it. Thus, in the history of human flight, less attention is generally paid to the early experiments than to the events which immediately followed their successful conclusion, and it is thought that the reader will appreciate the emphasis which has been laid here on those experiments. The survey is by no means exhaustive, but it covers the more outstanding achievements. There were other pioneers—men of distinction in the sciences who were attracted by this seemingly insoluble problem. For example, Sir Charles Parsons (1854–1931) experimented in 1893 with model flying machines, achieving a measure of success*, and Dr. F. W. Lanchester evolved, in 1894, aerofoils and model gliders in connexion with his early research in the subjects of aerodynamics and stability—an enquiry which led to his very profound contributions to the theory of flight; see p. 135. (Footnote)

To what extent a study of the historical background serves to elucidate the development of an idea is perhaps a moot point, but in this case it cannot fail to facilitate an understanding of the subject. At the close of the nineteenth century, the problem of human flight, analogous to flight in Nature, remained unsolved; its achievement appeared, to all save a few, as a quest fantastic and irrational mainly because the principles which could underlie it were not

* *See* "Nature", 18th June, 1896.

generally understood. This attitude explains, to a great extent, why those who investigated the subject of dynamic flight and attempted to imitate it were unable to obtain the support which would have been accorded to practically any other enterprise in that enlightened age. As ever, the vision of a few transcended that of orthodox thought, and those such as Henson, Stringfellow, Pénaud and Langley were doomed, if not to failure at least to discouragement.

IX. EXPERIMENTS IN GLIDING AND SOARING FLIGHT

1890–1903

IT HAS BEEN SHOWN in the previous chapter how the aeroplane was formulated in various designs, and how, by experiments with models, it was proved that a heavier-than-air machine could support itself in flight by virtue of the power contained in it. During the last decade of the nineteenth century a new school of thought arose which held the opinion—probably as a result of those experiments which, though successful on a reduced scale, had not so far culminated in human flight—that actual practice in the air was the best method of solving the problem, or even that it was essential to the solution. Thus the era of practical experiment in the air began—a revival of the earliest idea of trial with artificial wings, but on a different basis, *i.e.* on the natural phenomena of gliding and soaring and not of flapping-wing flight. These experiments, which were made to obtain knowledge of the behaviour of machines in the air as a preliminary to the application of power, covered the last decade of the nineteenth century and have continued to the present day. Though earlier experiments of the sort were made by Cayley and others, the real beginning of the modern movement was in the year 1890 when Otto Lilienthal constructed his first glider.

A glider is a heavier-than-air aircraft (aerodyne) with fixed wings which is not mechanically driven—an aeroplane without an engine. In default of any engine sufficiently light and powerful for mechanical flight being available, it is obvious that the only means of practice in the air was with motorless machines, and at least it served to fill the interim period between the invention of the internal combustion engine and its development, production and adaptation for aircraft. There is also the human factor to be considered; the factor which Gustav Lilienthal expressed so eloquently in the preface to his brother's book: " The glory of a great discovery or an invention which is destined to benefit humanity, appears to him [man] the more dazzling the closer he approaches it; he perceives not the thorns in that crown, he heeds not its weight, but his whole life is shaped to attain it."

In gliding, it is possible to approach very closely to the ideal of mechanical flight; it is possible to learn something of the air and of its currents and the reactions of a machine to them. Let it be clear that the underlying principles of gliding and soaring flight are the same as those of mechanical flight, though gravity and the air currents take the place of the motor, but the latter has additional principles involved by reason of the employment of a propulsive force and the necessity for more adequate control. The pioneers of this art were mostly united in the belief that a bird-like efficiency might one day be reached—as, indeed, it nearly has been—and their gliders were modelled largely on nature, it being thought that when the problems of equilibrium and control had been mastered it would be possible to construct a machine which would require but a slight propelling force to maintain it in horizontal flight.

The history of gliding and soaring flight may be divided into three periods. The first, as already stated, began with the work of Lilienthal,

though some investigators who immediately preceded him helped, by their observations of bird flight, to lay the foundations; the objective during this period was, of course, the attainment of human flight. The second period was that of only sporadic activity with motorless machines, which extended from the time of the first mechanical flight (1903) up to the year 1919, when the third and modern period of gliding began. It is significant that the first and last periods of experiment with motorless machines began in Germany; the urge to fly was, in both cases, profound, though in 1890 it found expression in two brothers and in 1919 in the youth of a nation. The causes were much the same; the desire for knowledge and progress, and the fact that no engine was available at the time. In 1919 Germany, under the Treaty of Versailles, was prohibited from making any expenditure on military aviation, and in consequence she directed her energies to the design of efficient transport machines. The Treaty restricted the production of aircraft and thus hindered activity on normal lines, so that other methods were sought and a revival of gliding took place. The objective was not, as at first, merely the attainment of flight, as that had long since been accomplished, but the advancement of aerodynamic knowledge and the acquiring of " airmindedness." A great store of technical knowledge had been accumulated since the first gliding experiments were made, and this was applied in the construction of improved motorless machines with the resulting accomplishments of soaring flight and remarkable performances. Gliding competitions were held regularly in Germany, and later took place in England and France, until the modern movement was established as it is to-day.

The earliest gliding was confined to utilizing the force of gravity in descent from a height; this was followed by elementary soaring when the force of an up-current, encountered during a glide, was taken advantage of to support the machine. The technique of soaring and " sailing " is essentially a recent accomplishment, for it depends largely on an advanced development in aerodynamic design. The modern method of launching gliders by catapult was unknown to the pioneers and their machines were unsuited to such treatment. Similarly the method of towing a glider with an aeroplane or motor car, preparatory to soaring or aerobatics, was not available, and the earliest attempts, as will be seen later, were confined to the experimenter himself with, perhaps, the assistance occasionally of others.

The investigations and experiments of two Frenchmen, Jean Marie Le Bris (1808–1872), a sea captain, and Louis Pierre Mouillard (1834–1897), are worthy of special note because they immediately preceded the era of practical gliding flight and the influence of the latter's writings was indubitable. Both these men observed acutely flight in nature in its most highly specialized form and drew inspiration from it. They were deeply impressed by the phenomenon of gliding and soaring as practised by the albatross and other birds, and were stimulated to imitate it. Le Bris had observed the remarkable flight of the albatross during many voyages and he attempted to reproduce it in artificial form. Clearly he was convinced that wings could be made to support a man in the air, else he would not, one imagines, have constructed such a machine. It was built about 1856 and the arched surfaces measured about 50 ft. in span and were articulated to a body shaped like a *sabot*. The total supporting surface was about 220 sq. ft. and the weight 92 lb.; an arrangement of levers was employed to vary the inclination of the wings and tail.

An attempt was made, it is said, to launch the machine from a cart (drawn by a horse) to which it was attached by a rope, and this appears to be the first experiment of towing a glider. The statement that it rose on this occasion 300 ft., if correct, indicates that Le Bris was not in the machine, because in that event the wing loading would have been at least 4 lb. per sq. ft. on the basis of the figures given, and the experiment unlikely to have been successful. A full account is given by Chanute, which, he states, is derived from two earlier publications of G. de la Landelle, the first a novel and the second a record of aerial achievements.* Chanute hesitated to accept the account in the novel as evidence, but he glibly accepts the "historical book" as confirming the accuracy of the former, though it was written six years later. The account is not convincing and, as such, unfortunately deprived the experiments of the instructive value they might otherwise have had.

Mouillard stands out as a great apostle of gliding flight. His investigations covered a period of some thirty years and he recorded his observations of flight in nature and his conclusions in a remarkable book, "L'Empire de l'Air," published in 1881. This work was widely read and its fervour was one of the inspiring causes of later experiments; it was studied by Chanute and by the Wright brothers, who did not hesitate to acknowledge the inspiration they drew from it. Mouillard was unsuccessful in practical experiment, his apparatus being somewhat crude. He took out a patent in 1897—the year of his death—for the design and control of heavier-than-air machines and constructed a final glider at Cairo, but it was too crude in workmanship to permit of actual gliding flight. He fills a particular place in the history of aviation; he was not a mathematician or an inventor in the accepted sense and was unable to realize his ideas, but he had a great enthusiasm and a fervour which is manifest in his first book and in the subsequent "Le Vol Sans Battements," which he was writing at the time of his death; these are enduring evidence of his intellectual qualities.

Otto Lilienthal (1848–1896) was undoubtedly the pioneer of gliding flight and one of the principal contributors to the knowledge and confidence which subsequently made mechanical flight possible. Born at Anklam, in Pomerania, on May 24, 1848 (the year in which Stringfellow demonstrated that a model could fly under its own power), he entered the Potsdam Technical School in 1864, and was a student at the Berlin Technical Academy from 1867 to 1870. He served in the Franco-Prussian war and was subsequently employed in machine shops in Berlin, where, it is said, he displayed great skill in work requiring precision. It is significant that he passed the final examination at the Technical School, "with the highest honours over attained by any previous scholar," because it shows that there was the somewhat rare combination of mental ability and manual skill which appeared necessary in the problem of flight. One cannot imagine the success of the Wright brothers, a few years later, without such a combination of talents which they too possessed in a high degree.

The best account of Lilienthal's experiments is contained in his own published work, "The Flight of Birds as the Basis for the Art of Flying"† and the information given here is extracted from the English translation of 1911.

* "Les Grands Amours," 1878, and "Dans les Airs," 1884.

† "Der Vogelflug als Grundlage der Fliegekunst," Berlin, 1889. An enlarged edition was issued in 1896. A further account is given in "Otto Lilienthal—Der Erste Flieger," by Gerhard Halle, 1936.

Gustav Lilienthal relates in the introduction how he and his brother Otto were stimulated at an early age by a fable in which the Stork explains his method of gliding flight, and the opportunity to observe those birds in their natural state was provided in the country surrounding their native town. Thus interest extended to the whole animal world and they examined the flight of insects, particularly butterflies, but the stork appears to have impressed them most. In 1861 their father died, and it seems that at about that time their first experiments, made with wings measuring 2 metres by 1 metre, constructed of thin beech veneer with straps, through which the arms were placed, were undertaken. This was when Otto Lilienthal was fourteen years of age, and, as his brother remarks, they "met with no success."

This interest was, however, sustained during the next twenty-five years, though the opportunities for research and experiment were restricted by employments which separated them and involved regular correspondence for exchange of ideas. The collaboration of the two brothers during this period, and later, brings at once to the mind the analogy of the brothers Montgolfier and the Wright brothers already referred to, and the coincidence (if it is such) that the greatest achievements in the early history of flight resulted from the co-operation of brothers obtains a greater significance. Otto Lilienthal, it is clear, was the more able and inspiring force, and, even apart from the gliding experiments which followed, the main work of investigation is rightly regarded as his. His first situation was in the machine works of Weber in Berlin; later he occupied the post of designer in the engineering works of C. Hoppe and travelled extensively in connexion with the introduction of new machinery in mines. The merit of his work in aeronautics lay essentially in the application of mechanical training to the elucidation of the problem of bird flight. He abstracted some order from the existing confusion of thought and reduced that which was previously obscure and mysterious to the form of a dynamical proposition. His book was virtually a textbook, and it was the first work on mechanical flight which may be so described. It enabled those who followed him to proceed on *definite* lines and elaborate the theories he had advanced. In the light of later experiments, with increased facilities, some of Lilienthal's conclusions were superseded, but this does not detract from the great merit of his work as a whole—work which inspired others and was followed up by investigators such as Chanute, Pilcher and the Wright brothers.

It is obviously beyond the scope of this book to describe that work in detail. The year 1889 was marked by the publication of the practical results of those twenty-five years of research and study, and Lilienthal stated thirty fundamental conclusions with regard to the construction of flying machines. He demonstrated that curved wings were much more effective than flat ones and tested a variety of wing shapes, obtaining data regarding the forces set up by their motion through the air. In these experiments a machine was employed to rotate the surfaces, but Lilienthal showed that he appreciated the limitations of that method, which is inferior to the more modern one of measuring the reactions of a surface mounted in an apparatus for producing a uniform stream of air, *i.e.* a wind tunnel. It should be noted that the basis of this research was to discover the particular virtues of different natural wing shapes; in fact Lilienthal's early investigations were directed wholly to an exact understanding of the phenomenon of flight in nature. The aerofoil

sections which he later defined were developed from and simulated the cambers of birds' wings. He investigated the movement of the centre of pressure on a surface during flight and the problem of maintaining stability with an artificial gliding apparatus, in addition to the question of the power required for flight and many others.

In 1891 he began the series of gliding experiments which, as already remarked, constituted the first attempt to discover the behaviour of a man-carrying apparatus in the air. His first glider had a supporting area of about 107 sq. ft. and weighed about 40 lb. In 1893, with a glider weighing 44 lb. and having a total area of 150 sq. ft., he made successful glides from an artificial hill, 50 ft. high constructed for the purpose at Gross Litcherfelde, near Berlin. Lilienthal's gliders were all monoplanes with the exception of the last, and based, as already stated, on the wings of a bird. The wings, which could be folded for transport, consisted of cotton fabric stretched on willow ribs which were hinged from the extremities of a horizontal member to which were attached two upright members about 6 ft. apart. The two uprights formed king-posts from which a number of wires radiated to the upper surfaces of the wings and similar bracing wires radiated to the under-surfaces from the extremities of the horizontal member beneath; these wires braced the wings when in flight. The pilot occupied a position in the centre where the fabric covering was cut away and he was supported under the forearms by two small bolsters enclosed in armlets attached to the main frame. The body was thus supported in a vertical position with considerable freedom of movement, and the method of launching was to run forward from the summit down the hill into the wind until the air-pressure due to the wind and the motion was sufficient to sustain the machine. Actually the support was derived mainly from the wind, the initial forward speed being slight, and in consequence all successful glides were made when there was an appreciable breeze. A tail, in the form of fixed horizontal and vertical surfaces, was always employed and control in the air was, except during the final experiments, effected solely by movements of the pilot's body (movement of his weight in relation to the machine) to correct changes in attitude of the glider due to movement of the centre of pressure on its wings. In other words, the only means of maintaining equilibrium was by constant movement of the body, requiring much skill and practice.

Hundreds of steady glides were made, however, from the slopes of the artificial hill, a distance of over 100 yds. often being traversed at an angle of descent of 1 in 7 or even less. Lilienthal had flown (or rather glided) nearly horizontally in winds of about 20 m.p.h., and in high winds he frequently allowed himself to be lifted from the hill without the necessity for running down the slope; in fact he often found himself higher than its summit. It is obvious that these experiments enabled very useful information to be obtained concerning the behaviour of a heavier-than-air machine and Lilienthal, by using gravity and the air currents as motive power, established the then only possible way of approaching practical mechanical flight. He demonstrated that it was possible to experiment in the air, and showed how a knowledge of the behaviour of a plane surface and the rudiments of control could be obtained and were the first requirements to success. Stated in the most simple terms, Lilienthal's achievement was that of creating confidence in the idea of mechanical flight. The inspiration drawn by the Wright brothers, and many

others, was essentially that flight was no longer a fantasy since Lilienthal had placed it upon a practical basis.

In 1896 he adopted two superposed planes (actually two gliders attached to one another) having a span of 18 ft. and providing an area of 200 sq. ft. During the same year he went to the Rhinower Hills, near Stöllen, and accomplished glides of 750 ft. and more. Unfortunately in August 1896 he met with a serious accident, his machine being caught in an awkward current while he was experimenting with a horizontal elevator plane operated by moving his head. The confusion which resulted from the new control at a critical moment caused the machine to fall heavily from a height of 50 ft., and Lilienthal died a few hours later from the injuries he received; thus closed a life of great distinction in the history of flight. The fact that photography was available when Lilienthal's experiments were made was most fortunate, because it provided a visual record which was completely convincing. Many excellent photographs were taken, and one is reproduced here on Plate XVII.

It is understandable that Lilienthal should have had imitators. He inaugurated the era of practical experiment and was followed in Great Britain by Percy S. Pilcher (1866—1899), who was an engineer and lecturer at the University of Glasgow. Pilcher was a close follower and adopted generally the manner of Lilienthal's design, but with the important difference that his first machine, the "Bat," built in 1895, had a very pronounced dihedral angle, the wing tips being raised 4 ft. above the body to assist lateral stability. He also demonstrated the advantages of a wheeled chassis, or undercarriage, to relieve the pilot of the weight of the machine and also to absorb some of the shock when landing. Pilcher, who visited Lilienthal in Germany, appears to have possessed all the skill of the latter and he too considered the possibilities of supplying mechanical power to his gliders, and, it is said, actually had an engine of 4 h.p. under construction when on September 30, 1899. his experiments were cut short by a fatal accident due to the collapse of the tail of his machine.

The next stage in the development of a stable and controllable machine was that initiated by Octave Chanute (1832–1910) in the United States of America. Chanute, born in Paris on February 18, 1832, went to America at the age of six and was trained as a civil engineer. In 1872 he became a chief engineer to the Erie Railroad, and it was when over sixty years of age that he began to investigate the subject of flight. He published in 1894 his book "Progress in Flying Machines," already referred to, which was a most comprehensive survey of practically all the ideas and projects which had been advanced in connexion with mechanical flight. The value of this book as a record in a convenient form of the endeavours already made was—and is to-day from the standpoint of history—considerable. But it was restricted to what had already been done and was not primarily constructive. Chanute's own experiments were directed to improving the control of a glider and he proposed to correct loss of balance by making the main supporting planes movable in a fore-and-aft direction, and by so doing to restore the centre of pressure to a position which would promote stability, instead of maintaining balance by moving the weight of the body, or centre of gravity, to coincide with the altering centre of pressure as Lilienthal and Pilcher had done. His theory represented an important advance and in 1896–1897 he attempted to test it by constructing a series of gliders differing widely in form and

arrangement of surfaces.* In these experiments he was assisted by A. M. Herring, a former pupil of Lilienthal, whose services he secured for piloting his gliders; the experiments were made near Lake Michigan.

The final type, arrived at after numerous modifications, was a biplane having equal sized planes with a tail arrangement consisting of combined horizontal and vertical surfaces, and these latter surfaces could, apparently, be flexed. The outstanding feature of Chanute's gliders was the introduction of *movable* planes for the purpose of control and stability; this was admittedly a step in the right direction and his system of making the main supporting surfaces movable was in 1935 adopted with success in the small type of aircraft known as *Pou du Ciel*. It is not, however, the method accepted as most satisfactory or likely, for various reasons, to be adopted generally, the conventional form of longitudinal control with a tail plane and movable elevator in the rear proving more satisfactory.

It is probable that Chanute's most valuable service in the cause of flight was his conveying of information from Europe to America. His book alone made available a great fund of knowledge (such as it was) and record of experiment in an easily assimilated form. In addition, he brought the stimulus of Lilienthal's gliding achievements to the United States and by his experiments in the same field may be said to have founded the movement in that country. His record as an engineer was one of distinction, and his interest in mechanical flight must have added weight to the subject.

In the author's opinion, the investigations of Octave Chanute definitely transferred the ascendancy from Europe to the United States of America. It will be recollected that Langley's most successful experiments with models were undertaken in 1896, the year during which Chanute began his gliding, and the double event marks the beginning of the period which produced human flight. It is not too much to say that the state of knowledge and of limited achievement in America, in the year 1896, was such as to make more understandable the success of the Wright brothers which followed shortly afterwards. In adopting this view we must take into consideration factors other than those of ascertained knowledge and of limited experience. The problem of flight came late to America; it was approached with all the enthusiasm and energy characteristic of the New World and appropriate to a new subject. There was no local record of failure because very few, if any, attempts had been made, and so there was not the extreme discouragement of the negative feeling which was so prevalent in Europe.

Professor John J. Montgomery of Santa Clara College in Calafornia also undertook experiments with gliders—his first experiments, with ornithopters, began in 1883—and he appears actually, to have been the first to practise gliding in America, but without marked success. In England José Weiss (1859–1919) explored the possibilities of automatic stability by the use of natural forms—a continuation of the work of Lilienthal which he began about 1896. He constructed numerous model gliders, and later (1909) full-scale apparatus, prior to evolving a design which incorporated a high degree of inherent stability; he followed Pilcher in England as an exponent of the method of investigation by gliding flight.

* *See* "Gliding Experiments," by Octave Chanute, delivered before the Western Society of Engineers (U.S.A.), October 20, 1897.

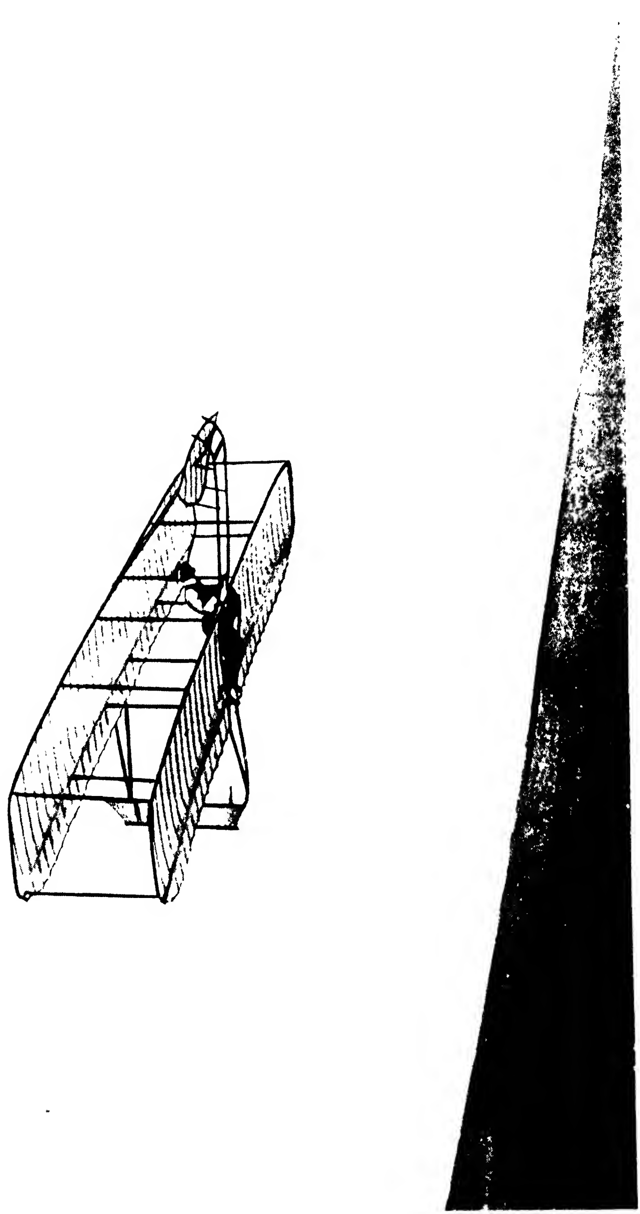
We are now about to enter upon the second great period of achievement in the history of human flight—the achievement by man of controlled and sustained flight in an aeroplane. The period is that of the Wright brothers and an endeavour will be made to describe it in a manner appropriate to its importance and influence. The brothers Wilbur and Orville Wright were the sons of Milton Wright, Bishop of the Church of the United Brethren of Christ, and members of a family of New England stock whose ancestors emigrated from this country during the seventeenth century. Wilbur Wright was born near Newcastle, Indiana, on April 16, 1867, and Orville Wright at Dayton, Ohio, on August 19, 1871. Two elder brothers, Reuchlin and Lorin, and a younger sister, Katherine, completed the family. Bishop Milton Wright has been described as a broad-minded father who encouraged his children to expand their thoughts, not placing obstacles in the way of their development, but awakening and guiding their latent talent. He had settled in Dayton, and there the two brothers, who will be forever famous grew up inseparable in their youth and manhood. Though Wilbur may have possessed the greater driving force, yet their merits and talents, unfolding as the years passed and they reached matured manhood, kept pace and identity with remarkable evenness. In this light and circumstance their great work can be regarded as only as a single achievement.

The collaboration of brothers, which is so notable in the history of flight, finds here its fullest expression; their unity of purpose and effort was remarkable. Both were distinguished by their spirit of enterprise. Printing, journalism and the manufacture of bicycles—the latter with marked success—seems to have occupied them until the development of their aeroplane claimed their whole time. Wilbur Wright stated that his own active interest in aeronautics dated from the death of Lilienthal in 1896, but it is also recorded that a toy helicopter, of the kind which Sir George Cayley used, was presented to the brothers by their father in 1878, and it probably served as an inspiration in early childhood. When reflecting on the problem of flight the brothers came to the conclusion that the main reason why it had remained so long unsolved, apart from the need of an engine, was that no one had been able to obtain sufficient practice in the air. They estimated that Lilienthal during five years of experiment had spent only about five hours in the air. The remarkable fact was " not that he had done so little, but that he had accomplished so much."*

It is clear that the work and writings of Lilienthal impressed them, and also the fact that Langley, a man of eminence in the scientific world, had declared his belief in the possibility of mechanical flight. They also paid tribute to the pioneer work of Stringfellow, but were, it seems, more impressed with the long list of failures than the meagre success attained by other investigators. In response to a request for books on the subject, they had received from the Smithsonian Institution at Washington a recommendation of " Langley's Experiments in Aerodynamics," Chanute's " Progress in Flying Machines," and other publications. A study of these books revealed, as Wilbur Wright expressed it, that " there was no flying art in the proper sense of the word, but only a flying problem," and that " the problem of equilibrium had been the real stumbling block in all serious attempts to solve the problem

* " Some Aeronautical Experiments," by Wilbur Wright, *Journal of the Western Society of Engineers*, Vol. VI, No. 6, December 1901.

PLATE XVIII

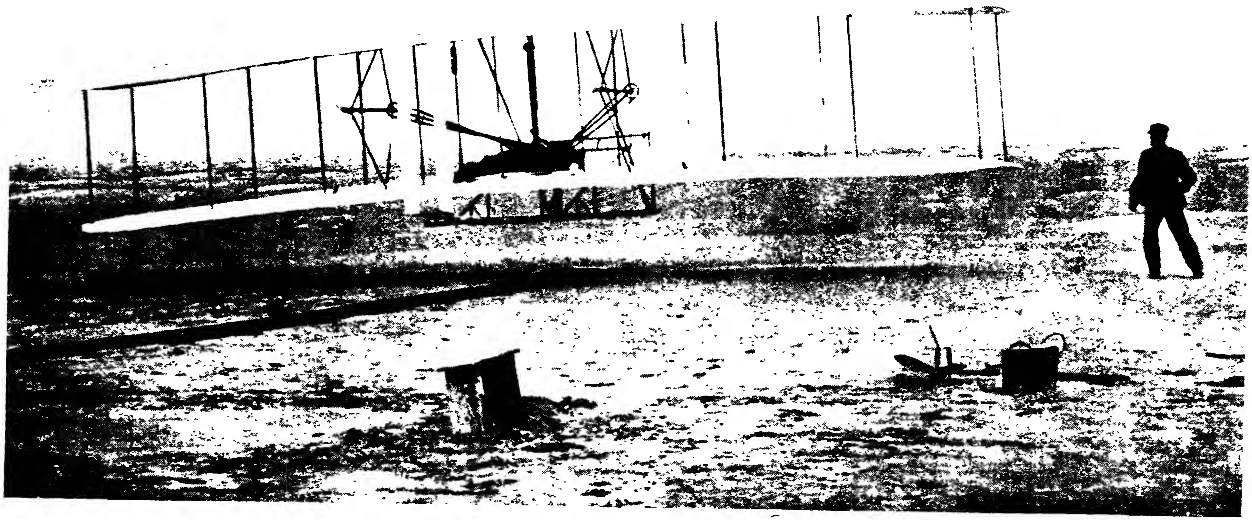


Wilbur Wright piloting the Glider of 1902

As the result of their gliding experiments the Wright brothers evolved a system of control and designed a machine which required only an engine to complete it

See Page 107

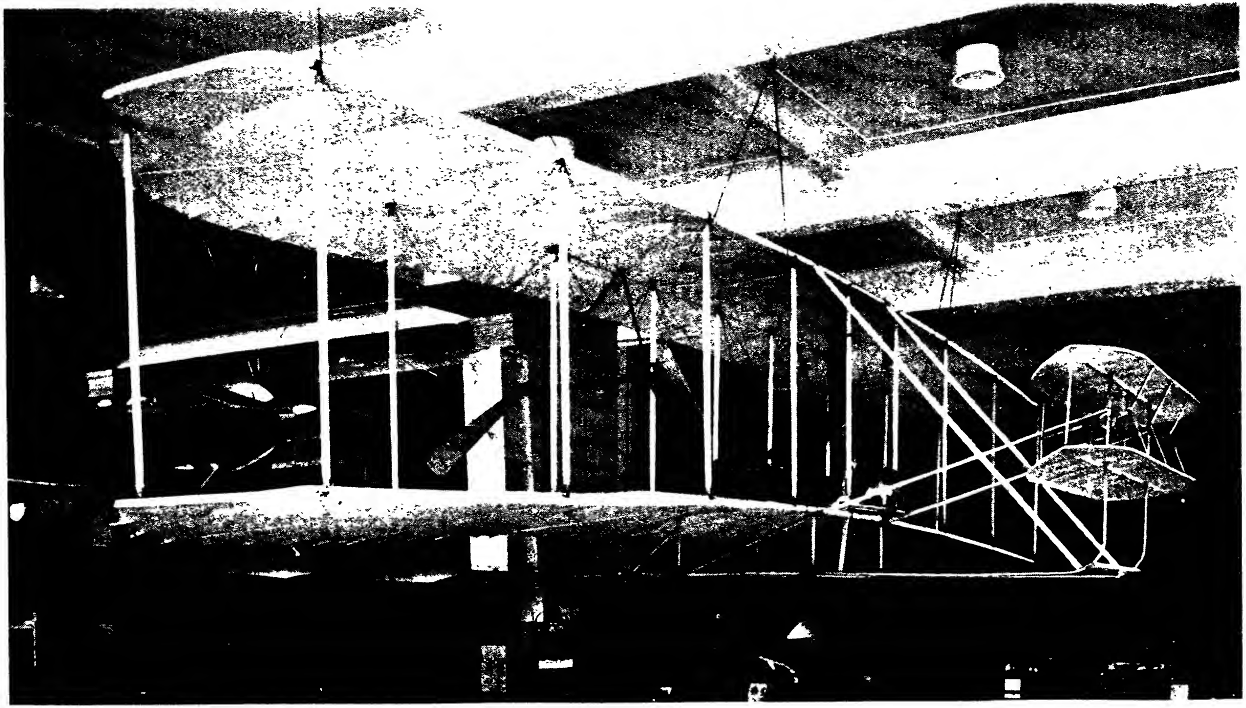
PLATE XIX



The "First Flight," December 17, 1903

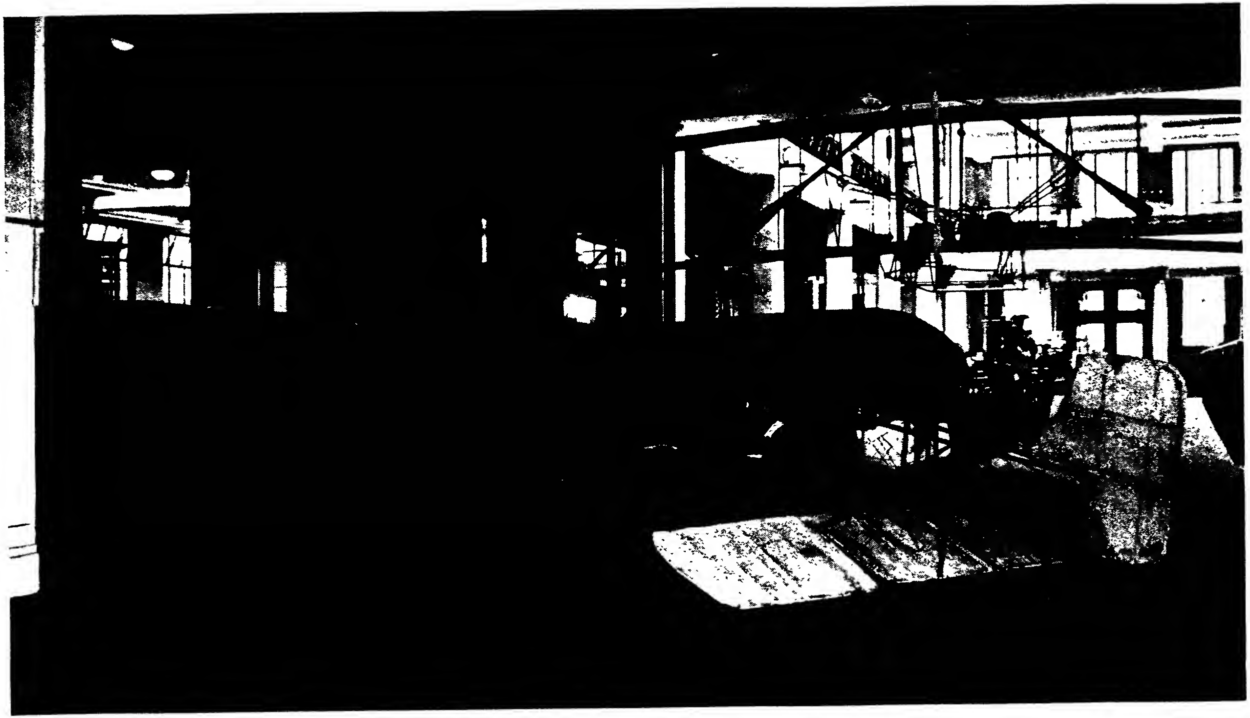
The first controlled and sustained flight in a heavier-than-air machine. Orville Wright piloting, Wilbur Wright *on foot*. The ground speed was 10 m.p.h. against a wind of about 22 m.p.h. *See Page* 116

PLATE XX



The Original Wright Aeroplane in the Science Museum, 1932

The Supermarine Rolls-Royce Seaplane (S.6B) which attained a speed of 407.5 miles an hour is in the background. See Page 116



The Monoplane in which Louis Bleriot crossed the Channel, July 25, 1909

The machine is shown in the Science Museum on the occasion of the twenty-first anniversary of the flight: the Wright biplane of 1903 is in the background. *See Page* 124

of human flight, and that this problem of equilibrium in reality constituted the problem of flight itself."*

We shall see how speedily the Wright brothers grasped the essential problem. Their train of thought, and the work of research and experiment which led to the first achievement of flight, has been described by them in accounts which are now classic. A valuable paper contributed to the Royal Aeronautical Society by Mr. Griffith Brewer in 1916 (the fourth Wilbur Wright Memorial Lecture) enlarged that record, and by publication of the earlier writings as an appendix made them more readily available in this country.† It is unfortunately beyond the scope of this book to describe every stage in the development of the Wright aeroplane, and the reader must be referred to the original accounts which convey, more vividly than any abstract can do, the essential genius of the work. These notes will be confined therefore to the outstanding stages in the evolution of the Wright machine, which, as all the world knows, began as a glider and ended up as a complete and successful aeroplane.

The attitude adopted by the Wright brothers was that every theory previously advanced must be tested and proved by practical experiment, and the courage and thoroughness of their work has been described as a perfect example of the way in which research should be conducted. Their grasp of the fundamental question of stability was the basis of their success, and they constructed three gliders in the process of evolving a form of control which would enable stability to be maintained. The use of vertical and horizontal rudders for control had long ago been suggested and applied—the development of those devices has already been described—and the setting of planes at a dihedral angle for lateral stability was a well-tried device. There was however, no proved method of controlling a machine laterally by *positive* action of the pilot, and it was the development of such a device which was the fundamental of the Wright brothers' invention. They stated that, from observation of bird flight, they came to the conclusion that in nature lateral balance was controlled by utilizing dynamic reactions of the air rather than by movement of weight, and in consequence they formed the opinion that a structure consisting of two rectangular superposed planes rigidly trussed along their front and rear margins, but not trussed from front to rear, would provide a means of flexing or distorting the surfaces on the analogy of the bird's wing as they observed it in flight. Modification of the idea resulted ultimately in a structure in which both ends of the upper and lower surfaces could be flexed, or warped, in unison, so that when one extremity was raised the other was lowered and *vice versa*. In operation it was quite simple; if one pair of wings dropped for any reason the control was applied so that their rear extremities were lowered, thereby increasing the lift on that side, while some decrease of lift on the other side, due to the raising of wing extremities there, further assisted the return of the wings to the normal horizontal position. The slowing down of the wing, the lift of which had been increased, was counteracted by opposite application of the rudder, the controls being interconnected. The linking of the wing warping control with the rudder control was the fundamental of the Wright claim. It is important to obtain a clear idea of this device in order to understand all of that which follows. The invention formed the

* Testimony made by Wilbur Wright, February 15, 1912.

† *The Aeronautical Journal*, Vol. XX, No. 79, July-September 1916.

subject of the Wright master patent, which, as will be seen later, had an important influence on the development of aircraft.

The idea of superposed rectangular planes was, of course, not new. Cayley had suggested "two-deckers" and "three-deckers" in 1843, and the Wright brothers acknowledged Wenham's later proposal. The aspect ratio they adopted was roughly that proposed by Henson at an even earlier date. Their skill lay in the selection and application of methods which they themselves proved, to their own satisfaction, to be sound. It is of interest to note that they did not apply the principle of the dihedral angle because they considered that it tended to produce oscillation, and was, moreover, restricted in usefulness. The same principle applied for longitudinal stability would, they considered, tend to constant undulation on the flight path; consequently they designed a machine which had no self-righting tendency, but depended wholly on controls for the maintenance of stability.

The first Wright glider was completed in 1900 and was tested near Kitty Hawk, a little settlement on the coast of North Carolina. The brothers had been advised by the Weather Bureau at Washington that strong and constant winds prevailed in that part of the Atlantic seaboard and the locality was selected for that reason. It was a desolate stretch of soft sand dunes relieved only by little elevations known as the Kill Devil Hills—a spot destined to become, three years later, the scene of historic achievement. They took a tent with them and the assembling and completion of the glider was done in it. The machine had a total wing area of 165 sq. ft., which according to the calculations of Lilienthal would be supported at an angle of 3 degrees in a wind of about 21 m.p.h. The result was very different to that anticipated and it appears that at this stage the Wright brothers decided to review the whole question, making measurements of "lift" and "drift" under various loads and forming their own conclusions as to the best shape for supporting surfaces. In addition to gliding experiments, the machine was tested as a kite, the controls being operated by cords from the ground. When gliding, the method of warping the planes to maintain lateral stability was found more effective than that of moving the pilot's body. Additional control was provided by a horizontal elevator plane in front, which they regarded as most satisfactory because it was most effective, and the pilot occupied a prone or horizontal position in the machine in order to reduce wasteful resistance; formerly all gliding had been done in an upright position. Above all, they formed the conclusion that "practice was the key to the secret of flying," as indeed it must have been in the Wright machines, which, as already remarked, were deliberately designed to have no self-righting properties.

All the knowledge gained was carefully tabulated and used in the design of the second glider, which was tested during the summer of 1901. It was larger, the total area being 308 sq. ft. (main planes, 290 sq. ft., front elevator, 18 sq. ft., subsequently reduced to 10 sq. ft.), the two planes having a span of 22 ft. and a chord of 7 ft., giving an aspect ratio of slightly more than 3 to 1. Experiments with this machine were at first disappointing and it was found to be due to excessive curvature of the planes; modification produced better results, but Wilbur Wright described the season's work as far from encouraging. Chanute, who had visited them previously, considered that the results obtained were better than any of their predecessors, but the brothers had lost faith in the data which existed and they decided to rely in future

solely on their own investigations. This was characteristic of them and it marks an important stage in their work.

On their return to Dayton they began the wind-tunnel research which constituted the basis for further development. The details cannot be described here and it is sufficient to say that over 200 model planes were tested, many in more than one scale, to determine what difference, if any, might be due to scale effect. The thoroughness of this research was typical of the Wright brothers' whole work; nothing was left to chance, everything was tested and verified. The sum of the results was incorporated in the third glider (1902), which may be considered as the prototype of the Wright brothers' first aeroplane. It was tried at Kitty Hawk in September 1902, had a total area of 305 sq. ft. and a weight with pilot of 250 to 260 lb., giving a mean wing loading of 1.2 lb. per sq. ft. A vertical surface in the rear was now introduced, and was later made movable as a rudder and interconnected with the wing warping mechanism. Wilbur Wright described minutely the experiments and reasoning which led to the development of the complete control. It functioned admirably and nearly 700 successful glides were made during the two or three weeks following the machine's completion. It was flown in calm weather and in winds up to 35 m.p.h.; it was steered to right or left and, as Wilbur Wright remarked, " performed all the evolutions necessary to flight." By the end of the season nearly 1,000 gliding flights had been made, some covering distances of over 600 ft.

The Wright glider was now practically in the form pictured and described in the Wright Patent No. 821,393 (filed March 23, 1903, and issued on May 22, 1906). As already described, the pilot adopted a prone position on the lower plane. He operated the front elevator plane with his hands; in the final form this consisted in grasping and rotating, by means of a small hand lever, a bar which by a quadrant and control wires produced a fine movement of the double elevator plane. The mechanism for warping the main planes consisted in an ingenious arrangement of wires passing over pulleys and connected with a wooden saddle or " yoke " in which the pilot's body rested. A slight movement only of the body to one side or other was necessary to warp the wings and to impart an opposite movement to the interconnected vertical rudder in the rear. An idea of the general arrangement of the machine may be gained from Plate XVIII, which is one of several excellent photographs showing the Wright brothers' experiments.

The method of starting on a glide varied according to the speed of the wind, on which depended largely the choice of the position from which the launch was made. The first gliding, as distinct from kite soaring, experiments were made from the Kill Devil sandhill, some four miles from the camp at Kitty Hawk. This hill rose to a height of 100 ft. above the surrounding sand and sloped to the north at an angle of about 10 degrees. The glider was launched by the help of two assistants, and it was unnecessary, in fact impossible, for the pilot himself in his position to run forward in order to start a glide. It is understandable that, under these conditions, greater precision was possible in launching, and the pilot was quite free in his stationary position to operate the controls with accuracy. It will be recollected that, in much earlier experiments, the problem of launching a machine satisfactorily was by no means the least of those which had to be faced. Stringfellow's limited success depended largely on his device for starting his model and it will be seen that

the Wright brothers paid particular attention to the question when they came to fit an engine to their glider.

It is appropriate here, at the close of the experiments of 1902, to quote the Wright brothers' just claim for their invention. It applies as much to the glider in its final form as to the power-driven aeroplane which was developed from it. The essential part of the statement is as follows:

"This was the first time in the history of the world that a movable vertical tail [rudder] had been used in controlling the direction or the balance of a flying machine. It was also the first time that a movable vertical tail had been used, in combination with wings adjustable to different angles of incidence [*i.e.* wings warped in unison], in controlling the balance and direction of an aeroplane. We were the first to functionally employ a movable vertical tail in a flying aeroplane. We were the first to employ wings adjustable to respectively different angles of incidence in a flying aeroplane. We were the first to use the two in combination in a flying aeroplane."*

It will be seen that the first part of the Wright brothers' work was the development of a complete system of control—a fundamental to mechanical flight. It was the first part of the whole problem and the most difficult part—a *sine qua non* to success. No one would suggest to-day that their system was the best which could be evolved; but it was the first and it made controlled flight possible. The achievement was not, however, due alone to the perfection of a means of control; their wind-tunnel research was indispensable and enabled them to produce effective cambered wings of good aspect ratio and to determine the lift and drag values of such wings at flying angles—a subject where little reliable data was available. The phenomenon of the reversing of the centre of pressure on a curved surface and its location at different angles was explored by them, calculated, and accounted for in the design of their machine. Later they developed airscrews as the result of research in that subject, and finally they adapted and applied the petrol engine for the purpose of mechanical flight. Description of that part of their work comes most properly in the account of the first flight, and it will thus be found in the next chapter.

Before concluding these notes, mention should be made of some contemporary experiments in France. Captain F. Ferber (1862–1909) began in 1899 to experiment with gliders in the manner of Lilienthal, attempting to control his machine by movements of the body. He became acquainted with the work of Chanute and the Wright brothers and constructed a biplane glider on the lines they had laid down. Satisfactory glides were made during 1902 and 1903, and later an engine was applied but without immediate success. In England the Wright brothers and Chanute had imitators; the practice of gliding flight does not, however, appear to have led to an independent investigation of the subject of control.

The reader who has followed this account so far will agree with the statement that gliding experiments formed the basis of practical mechanical flight; certainly they were the means of ascertaining rapidly and safely the essentials for flight. The danger of applying an engine (had it been available) to the propulsion of a vehicle whose behaviour was unknown was thus avoided, and the economy so desirable in the development of a new invention was preserved. Later, when suitable power was available, there were many

* Testimony made by Wilbur Wright, February 15, 1912.

instances of engines being fitted to untried machines, and, according to some opinion, the proper development of aircraft was hindered by the application of power to inefficient, if not quite abortive, machines. The first study was that of aerodynamics; the second that of the application of power. Hence the Wright brothers were true pioneers of the aeroplane. Circumstances prevented a premature application of power, but, had they not, it is clear that the brothers would never have attempted to " run before they could walk," and the essential wisdom of their outlook, coupled with their genius, assured them success.

X. INVENTION OF THE AEROPLANE

(Second Great Period of Achievement)

1903–1912

IT WILL BE EVIDENT from the foregoing notes that the aeroplane was not first conceived, built and flown by one or even two men, but was evolved gradually over a period of about 100 years by several men of science, engineers and practical experimenters, each of whom contributed in some small measure to the accumulation of knowledge and experience which made mechanical flight possible. Nevertheless the aeroplane was invented (in the sense of successfully devised) by the Wright brothers, because they were the first to apply the existing knowledge in a manner which was favourable to success, to acquire further knowledge and to contrive a system of control which was effective. They were also the first to apply a suitable engine to a proved machine, and above all they were the first to accomplish free flight.

The " British Standard Glossary of Aeronautical Terms " (1933) defines " free flight " thus: " A power-driven aerodyne is in free flight when, having left the ground, it is maintained in the air by its own power on a level or upward path, for a distance beyond that over which air forces alone would sustain it." Clearly, " flight " is the movement of a body through the air unsupported from the earth; but such movement may be uncontrolled, partly controlled or controlled. " Free " (which postulates also " sustained ") flight with heavier-than-air aircraft is dependent on the machine used being under control. It is necessary to decide, first that the aviator was not merely projected into the air; secondly that he was not gliding, *i.e.* using the force of gravity with the possible assistance of air currents; and thirdly that the machine was under control. For " free flight " it is desirable that the aviator should demonstrate that his machine is capable of remaining in the air for a sufficient time to indicate that it could do so for a prolonged period; the final stipulation ensures that the power unit is a practical one capable of sustained output, and the control adequate. No apology is made for including these definitions because they have an important bearing on the question of who was the first to fly. It will be recollected that a claim was made in regard to Clément Ader's machine that it left the ground solely as the result of the engine contained in it, and thus made a flight, but it cannot be substantiated in the light of the now accepted definition. Similarly, Maxim's experiment was not flight because the machine was artificially restricted and there was no evidence that it could have been maintained in the air.

Unfortunately the early history of flight has been clouded by a good deal of controversy not only as to who was the first to achieve it, but also regarding the proportion of credit due to different individuals in the process of development. The latter is, of course, far more difficult to determine, and it is generally regarded as a function of historians in this subject to attempt an explanation. The issue is complicated by the contention that some machines which failed for various reasons to fly when tested were, nevertheless, " capable

of flight," and in one case a machine was reconstructed, modified and tested some eleven years after its failure, in order to prove that was the case. We are not concerned here so much with the apportioning of credit as with how the aeroplane was evolved and the influences which made it what it is to-day. Obviously the flying machine offered a great prize to the successful inventor who could establish and secure his claim, and the financial aspect explains a good deal of the controversy which raged around it. Actually the benefits from a great invention like the aeroplane could not be controlled by one man or one organization or even one country; patent litigation showed that was so. It was a case where the inventor might never receive the just reward of his labour because the invention was too important to be confined within the limits of personal ownership, and this fact will explain a good deal of the history which follows. Happily the controversy regarding ownership—which to a large extent obscured the far more important question of how the new invention was to be used—is now a thing of the past, and the main facts of the achievement and development of flight are fairly well established.

The events described in this chapter cover the years from 1903 to 1912, and constitute, as the title suggests, an outstanding period in history. It may be asked why the period is extended to the year 1912, because the invention of the aeroplane—if it can be said to have been " invented "—took place in 1903 and its development was not long delayed. The answer is that the aeroplane did not develop into a settled form for some years, and it was not until 1911 that there was any tendency towards standardization. The year 1912 marks the close of the first period of development, and it has been selected, for that reason, as the termination of this chapter.

It has been said that the Wright brothers began their work in the darkest era of aeronautical research. Lilienthal and Pilcher had lost their lives; Maxim, Phillips and Ader had failed. There remained, however, one investigator of note whose experiments were not concluded. It will be remembered that in 1898 Professor Langley was asked by the United States Government to undertake the construction of a man-carrying machine based on his successful model " aerodromes." Langley's first consideration was the type of engine to be used, and it was decided that the petrol engine had been sufficiently developed to justify its application for flight and that it would provide the maximum power for a given weight, compatible with a degree of safety from fire which could not be assured with the steam engine. This was in accordance with the general opinion at that time, which accepted the fact that the internal combustion engine in some form was the only possible source of power.* Finally, Langley instructed his very able assistant, Charles M. Manly, to design a suitable engine, as an order placed outside was not fulfilled. Manly evolved a five-cylinder, water-cooled, radial engine which developed about 50 h.p., the weight being as low as 3.6 lb. per h.p., including the radiator, petrol tank, ignition system and all accessories—a truly remarkable achievement at that time.

The design and construction of the full-scale " aerodrome," as Langley designated it, occupied the years 1899 to 1903, the period during which the Wright brothers were making their experiments, and it must thus have acted

* The period 1896-1898 was one of intensive development of the automobile, when the petrol engine was subject to practical test on the road.

as a stimulus to their independent endeavour. The machine was based on the most successful model of 1896, which has already been described, but entailed additional experimental work and the careful execution of a vast amount of detail, a full account of which will be found in the "Langley Memoir on Mechanical Flight" issued by the Smithsonian Institution.

The trials, which were attempted over the Potomac River on October 7 and December 8, 1903, are described in the official report of Major M. M. Macomb, who represented the War Department, from which the following information has been extracted.* The total weight of the "aerodrome" on the occasion of the test was about 730 lb., which was to be supported by a surface of 1,040 sq. ft. (the span of the two pairs of wings was 48 ft. and the overall length of machine 52 ft.) and propelled by an internal combustion engine developing over 50 b.h.p. On October 7, when the first trial was made, the engine was observed to work well, but on attempting to launch the machine (from the top of a house-boat) the front guy-post caught, it is said, in its support on the launching car and was not released in time to permit of free flight, but caused the front of the machine to be dragged downwards, bending the guy-post and causing the machine to plunge into the water about 50 yds. from the house-boat. On the occasion of the second attempt, on December 8, a hitch again occurred in the launching, the rear guy-post appearing to drag and bring the rudder down on the launching ways, which was followed by the collapse of the rear wings, indicating, it is said, that the machine had been wrecked in the launching, just how it was impossible to say. The collapse of the rear wings and rudder deprived the machine of its support behind and the front portion reared up and the whole fell into the water a few feet in front of the boat.

These unfortunate accidents, which, Major Macomb said, prevented any test of the apparatus in free flight, and the consequent unsatisfactory result of the trials, together with a measure of hostile criticism, caused the United States Government to decide that it was not prepared to allot further funds for a continuation of the work. Langley, who died in 1906, had devoted some fifteen years to painstaking research and experiment; he had demonstrated that it was possible to construct a model aeroplane which could maintain itself in horizontal flight, and this was undoubtedly his greatest achievement. In addition, he recorded data in the whole field of aerodynamics, and though some of his conclusions may have been in error, his work, as a man of standing in the scientific world, served to inspire and give confidence to others.

In 1914 the machine, which was preserved by the Smithsonian Institution at Washington, was reconstructed with the addition of floats, and certain modifications and alterations were made with the object of submitting it to further tests in an endeavour to settle the question as to the original aeroplane's ability to attain free flight. The machine was induced to rise from the water on several occasions, but the conditions under which the trials were made aroused an acute controversy, which can be followed in the *Journal of the Royal Aeronautical Society*, December 1921. The trials were most regrettable because, as it was admitted that certain alterations were made and later another engine substituted, they were necessarily inconclusive, and it is difficult to ignore the suggestion that ulterior motives prompted the reconstruction, which,

* Official report of Major M. M. Macomb of the United States Artillery Corps, dated Washington, January 6, 1904.

it should be added, was under the direction of the engineer Glenn H. Curtiss and not the officials of the Smithsonian Institution.

The author hesitates to express an opinion on the merits of Langley's "aerodrome," because, owing to the many factors involved, it is not easy, or indeed very profitable, to speculate on it; the main consideration should, however, be pointed out. It will be appreciated that the method of launching was not satisfactory, and in the trials of 1914 floats were fitted for taking off from water. The machine lacked any positive method of lateral control in the form of wing warping or aileron device, and it would have relied mainly on the pronounced dihedral angle for lateral stability. Aircraft have, however, been flown successfully without aileron or similar control. The arrangement of planes in tandem has also proved quite successful, though probably inferior aerodynamically, and as recently as 1922 the late M. Manyrol demonstrated their efficacy under certain conditions. The tail arrangement (which, incidentally, was a form proposed by Sir George Cayley) was of a type later employed with some success, though not for long and only as an alternative to better established methods. We must regard the main planes as the most vital consideration in Langley's machine. The wing section employed was open, even at that time, to citicism, and above all the structural strength of the wings was a doubtful factor. It cannot be said that the design as a whole provided the basis for any subsequent successful development, and it is probably wisest to regard the "aerodrome" in that light. In 1942, the Secretary of the Smithsonian Institution published a report on the modifications made to Langley's machine for the trials of 1914, and also a correction of certain statements made at the time by officers of the Institution—more particularly those which described the machine as being the first aircraft capable of sustained free flight carrying a man. A long-standing dispute—known generally as the "Smithsonian-Wright controversy"—was thus happily composed and the credit of the Wright brothers completely established.

* * * * * *

We now approach the event which marked a new era in the history of mankind—the first flight in a power-driven machine, the possibility of which had been, in fact as well as in fable, a dream of the human race for centuries. No invention for utilizing the laws of Nature in the service of man had presented greater difficulties in application. By comparison with many more or less contemporary inventions, such as the telephone, the cinematograph and the transmission and reception of sound waves, which resulted from much patient research and skill in probing into the secrets of natural laws, the flying machine represents, in one sense, the greatest of all; for to solve the problem of mechanical flight it was necessary not so much to observe, as to learn how to defy the immutable law of gravity and actually to fly in the face of Nature.

To Wilbur and Orville Wright—whose courage and genius made it possible—was left the final glory of producing the first successful flying machine. They succeeded, by their own exertions, in doing what others were mainly thinking and talking about. After three years of practical experiment—an essential part of which was spent in the air—they had evolved a machine of proved efficacy which could be controlled in flight, and it remained only to apply the internal combustion engine, which invention above all made flying possible.

We resume the narative at the conclusion of the gliding experiments in 1902. In December of that year the brothers began work on the plans for a petrol motor for their glider. It was merely a motor-car engine simplified and reduced in weight and consisted of four water-cooled cylinders in line arranged horizontally. The engine was constructed mainly in the Wright workshop at Dayton, and it was tested there. The cylinders had a bore and stroke of 4 in., and the power developed was nominally 12 h.p. at 900 r.p.m., though on one occasion, under test, it is said 16 h.p. was recorded. The Wrights calculated that their machine would require at least 9 h.p. for flight at 25 m.p.h., and allowed a necessary margin. The weight of the engine, including flywheel and electric generator for ignition, was nearly 180 lb., or 15 lb. per h.p.

It will be recollected that the final form of Wright glider had a total supporting area of 305 sq. ft. and a mean wing loading of 1·2 lb. per sq. ft. In order to carry the engine, chain transmission and propellers, etc., the area of the first "Flyer," as the Wright brothers called it, was increased to 510 sq. ft., the span of the wings being 40 ft. and their maximum chord 6·5 ft. The total weight with pilot, fuel, etc., was about 750 lb., so that the wing loading in this case was approximately 1·5 lb. per sq. ft. In other respects the Wright aeroplane resembled the glider of 1902, but modifications in detail were made when necessary to the installation of the engine. The power was transmitted by chain drive to two propellers mounted in the rear of the main planes and driven in opposite directions to neutralize the effects of torque. It is stated that these propellers, which were the result of several months' research, gave a thrust efficiency of 66 per cent.—a marked advance on previous achievement. In addition to designing the engine, transmission and propellers, the brothers devised a very ingenious mechanism whereby a small anemometer of the fan type, and a stop watch, were made to record automatically the air speed and duration of flights.

The pilot adopted a prone position on the lower wing, as before, in order to reduce head resistance, and he operated the wing warping control, linked with the rudder, by twisting the hips in a yoke or movable cradle with which these controls were connected. The front elevator, which governed the ascent or descent and was used also to correct longitudinal instability, was operated by a small lever fixed to a rotating bar in front of the pilot. When starting, the aeroplane was placed on a two-wheeled trolley (the trolley consisted of a single bar fitted with two small rollers with another bar pivoted to it on which the undercarriage of the aeroplane rested) and driven along an iron-faced wooden rail in order to obtain easily the initial speed necessary for flight. It should be made quite clear that this device was employed in order to obtain a rapid and easy take-off by the aeroplane wholly under its own power. There was never any question of assisting the take-off on the first flights by means of a weight and derrick (a device which was later employed by the Wright brothers as a convenient way of getting a machine rapidly into the air), and the suggestion sometimes made that they were "catapulted into the air" is false. Finally, the speed of the aeroplane in still air was calculated to be 31 m.p.h.

The end of September 1903 found the Wright brothers again at Kitty Hawk for the final experiments. Octave Chanute and Dr. Spratt, who had previously given assistance, arrived about a month later, but were not present when the first flights were made. Various misfortunes overtook the brothers

in the form of twisted propeller shafts (which were made at first of steel tubing), bad weather and loss of a labour employee. By December, however, the machine was ready for final test, and so confident were they of success that they sent a general invitation to people in the neighbourhood to be present when the first flights were to be made. The cold December wind deterred all but five people from availing themselves of the invitation; they were John T. Daniels, W. S. Dough, A. D. Etheridge of the Life-Saving Station, W. C. Brinkley, a lumber buyer, and a youth, John Moore. On the morning of December 17, 1903, the aeroplane was brought out on to the sandy stretch at Kitty Hawk and between 10.30 a.m. and noon four flights were accomplished. The first was made by Orville Wright and it lasted but 12 sec.; the machine was, however, under control, maintained its height above the ground and landed without damage.

It is most appropriate here to quote the account written by Orville Wright himself for the Aeronautical Society of Great Britain. It is as follows:

"On the morning of December 17th, between the hours of 10.30 o'clock and noon, four flights were made. [Two by Orville Wright, and two by Wilbur Wright.] The starts were all made from a point on the levels, and about 200 feet west of our camp, which is located about a quarter of a mile north of the Kill Devil Sand Hill, in Dare County, North Carolina. The wind at the time of the flights had a velocity of twenty-seven miles an hour at 10 o'clock, and 24 miles an hour at noon, as recorded by the anemometer at the Kitty Hawk weather bureau station. The anemometer is 30 feet from the ground. Our own measurements, made with a hand-anemometer at a height of four feet from the ground, showed a velocity of about 22 miles when the first flight was made, and 20½ miles at the time of the last one. The flights were directly against the wind. Each time the machine started from the level ground by its own power alone, with no assistance from gravity or any other sources whatever. After a run of about 40 feet along a mono-rail track, which held the machine eight inches from the ground, it rose from the track and, under the direction of the operator, climbed upward on an inclined course till a height of 8 or 10 feet from the ground was reached, after which the course was kept as near horizontal as the wind gusts and the limited skill of the operator would permit. Into the teeth of a December gale the Flyer made its way forward with a speed of 10 miles an hour over the ground, and 30 to 35 miles an hour through the air. It had previously been decided that, for reasons of personal safety, these first trials should be made as close to the ground as possible. The height chosen was scarcely sufficient for manœuvring in so gusty a wind and with no previous acquaintance with the conduct of the machine and its controlling mechanisms. Consequently the first flight was short. The succeeding flights rapidly increased in length, and at the fourth trial a flight of 59 seconds was made, in which time the machine flew a little more than a half-mile through the air and a distance of 852 feet over the ground. The landing was due to a slight error of judgment on the part of the operator. After passing over a little hummock of sand, in attempting to bring the machine down to the desired height the operator turned the rudder too far, and the machine turned downward more quickly than had been expected. The reverse movement of the rudder was a fraction of a second too late to prevent the machine from touching the ground and thus ending the flight. The whole occurrence occupied little, if any, more than one second of time."

"Only those who are acquainted with practical aeronautics can appreciate the difficulties of attempting the first trials of a flying machine in a 25-mile gale. As winter was already set in, we should have postponed our trials to a more favourable season, but for the fact that we were determined, before returning home, to know whether the machine possessed sufficient power to fly, sufficient strength to withstand the shock of landings, and sufficient capacity of control to make flight safe in boisterous winds as well as in calm air. When these points had been definitely established, we at once packed our goods and returned home, knowing that the age of the flying machine had come at last."

The first flight was recorded in a remarkable photograph which has been reproduced more widely than any other picture illustrative of the history of aviation. It is reproduced here on Plate XIX. The aeroplane was left unattended after the last of the four flights and was caught by a violent gust of wind, overturned and considerably damaged before those present were able to secure it. It was taken back to Dayton for storage pending the issue of the patent already applied for. Some years later it suffered further from immersion during a flood at that city, and it was not until about 1926 that the work of renovating it for exhibition purposes was begun by Mr. Orville Wright.* In 1928 he lent the machine for exhibition at the Science Museum in London, where it remained for more than twenty years (*see* Plate XX).

Owing to the fact that the Wrights' experiments and trials were made in a remote and sparsely inhabited locality, where facilities for reporting on them were practically non-existent, it is understandable that newspaper accounts were inadequate and were largely disbelieved. In fact it was many years before their success at Kitty Hawk was generally known and accepted. Similarly, the experiments at Dayton which followed in 1904 seem to have been inadequately described and the Wright brothers did not receive proper credit for their achievements. It must be remembered that they worked under conditions of secrecy (as indeed nearly all the early experimenters did), and it has been said that even in 1907 the American public was largely unaware of their work. Everywhere scepticism prevailed regarding mechanical flight, and in Europe little credence was given at that time to the reports received. It was not until Wilbur Wright came to France in 1908 that the reality of their achievements were made known in Europe.

The making of improvements in the detail, design and construction of their aeroplane occupied the brothers during 1904 and 1905. In 1904 they made flights from a field near Dayton with a machine slightly larger than the original one and fitted with an engine of nominally 16 h.p. Unfortunately on the first public demonstration the machine failed to make a convincing flight, due to weather conditions and irregular running of the engine, with the result that the spectators were not favourably impressed and the genuineness of the Wright brothers' claims was not realized. The public reaction to the experiments appears to have been merely one of mild toleration, and though on September 20, 1904, they flew a complete circle in the air for the first time the full significance of the achievement was not apparently realized. On November 9, 1904, Wilbur Wright flew nearly four times round the 80-acre

* The machine had been reassembled and exhibited at the dedication of the Massachusetts Institute of Technology in 1916.

field in 5 min. 4 sec., this being recorded as the eighty-second power-flight accomplished.

The progressive increase in the duration of the flights gave evidence of development, and in 1905 a still larger machine with a total area of about 600 sq. ft. flew on September 26 for 18 min. 9 sec., covering 11·12 miles, and on October 4 for 33 min. 17 sec., covering 20.75 miles. The speed in still air remained as before, about 30 m.p.h.; the flights were undertaken at low altitude to reduce the risks, but it is unlikely that any considerable height could have been reached with the small margin of power available for climbing. Up to this time no one else had succeeded in making a free flight in an aeroplane and the Wright brothers were approached by agents of various interested parties who, it is hardly necessary to add, were concerned with the possible use of the invention for military purposes.* In October 1905 the Wrights had offered their invention to the War Department of the United States Government, but the offer was not immediately accepted and it was not until 1907 that they received a contract for the supply of a machine to carry two persons. A modification of the design was made and the pilot (and passenger) occupied a sitting instead of a lying position and the method of operating the controls by two vertical levers, one on either hand, was substituted for the earlier arrangement. These were definite improvements in detail; the fundamental features of the aeroplane remained the same (*see* Plate XXIII).

A good deal has been said in criticism of the Wright brothers' attitude when endeavouring to exploit their invention, but in the author's opinion much of it is unjust. They had expended the whole of their resources and the best years of their lives in devising and developing their machine, for which, in common justice, they deserved an adequate return. It is not desirable to attempt to trace here all vicissitudes of the next few years, and it is sufficient to say that the issue of the Wright patent in 1906 was followed by a number of imitative and collateral inventions which were the cause of much patent litigation. The invention—particularly the system for lateral control—was too valuable to be protected by the method of international patent law, and violation of the Wright brothers' claims was inevitable. The use of ailerons (movable flaps at or near each wing tip arranged to rotate in opposite senses) was regarded by them as an infringement of their device of wing warping, and it formed the subject of most of the subsequent litigation in which, it should be said, their contention was generally upheld. In 1907 competitors in the persons of Alexander Graham Bell (well known for his work in connexion with the telephone), Glenn H. Curtiss (1873–1930) and others were experimenting in the United States of America, but the consideration of their work and influence comes later in this chapter.

We must return now to Europe in order to trace the simultaneous development of the aeroplane there. It is somewhat obscured by reason of the fact that experimenters were in keen competition and consequently averse to the publication of details of their work. The history of this period is thus more complex than any other in the narrative of human activities in relation to flight. There were, of course, outstanding achievements, and it is the purpose of this book to attempt to interpret them.

* The armament competition of the opening decade of the twentieth century was stimulating to the development of the airship and the aeroplane, but, of course, less than the war of 1914–18.

The question as to who made the first free flight in Europe will probably always remain in doubt. The honours may be fairly equally divided between the Danish engineer J. C. H. Ellehammer and Alberto Santos-Dumont, whose achievement with airships has already been described. In the case of the former it is doubtful whether his first flight fulfilled the conditions necessary for free flight, but in point of time it preceded that of Santos-Dumont. Ellehammer certainly began the construction of his monoplane in 1904; it was fitted with an engine of about 18 h.p. and it was tested on a large circular track on the island of Lindholm. On September 12, 1906, it is said he accomplished a flight of 42 metres at a height of about 50 centimetres, but the feat is regarded by some as merely a hop. Nevertheless, during the next few years he accomplished flights of increasing duration and constructed a biplane and a triplane; the former, it is said, accomplished the first flight on German soil, at Kiel on June 28, 1908. The characteristics of Ellehammer's machines were the use of a tractor airscrew—he also employed a wheeled undercarriage—and control surfaces in the rear. It is thus unfair to say that his achievement led to no useful developments; in fact his design, though crude, was far more practical than that of Santos-Dumont, which was seldom, if ever, repeated.

Santos-Dumont's machine—named by him "14 bis"—consisted essentially of two box-kite structures, attached to a body or fuselage in which the pilot stood, and set at a pronounced dihedral angle to one another. Another movable box-kite structure was placed at the *front* extremity of the body and functioned both as an elevator and rudder. The engine, an Antoinette of 24 h.p. (later a 50 h.p. type was substituted), was placed in the rear and drove a pusher airscrew; a three-wheeled undercarriage was fitted. The total supporting surface was about 860 sq. ft. and the weight about 350 lb., so that the wing loading was under 0·5 lb. per sq. ft. in comparison with the loading of nearly 2 lb. per sq. ft. in the Wright machines; the weight per h.p. was only 7 lb. It is recorded that a flight was made on September 13, 1906, but it was at Bagatelle on October 23 that Santos-Dumont notified the Aero Club of France and performed a flight officially recorded as 25 metres, thus winning the Archdeacon Cup offered for the first flight in Europe; this record was increased to 220 metres during the following month. Santos-Dumont is therefore credited with the "first public flight" in Europe, but, had Ellehammer's flight been officially observed, the honour would probably be accorded to him. The "14 bis," with its "tail-first" arrangement, small wing loading, and absence of really effective control, cannot be regarded as a practical design, but it did show that flight could be accomplished with a powerful enough engine and it also marked the inception of the box-kite form of construction which endured for several years.

It must be clearly understood that development of the aeroplane in Europe, and particularly in France, was proceeding quite independently at this time (1906). The example of the Wright brothers was undoubtedly of great importance, but the influence was largely psychological because little exact information regarding their work had reached Europe. Later, when their achievements and the details of their design were made known, there was a direct influence apparent in many particulars of other designs, but in 1906 experimenters in Europe were going forward on somewhat different lines, the basis being generally the cellular or box-kite form of construction which Hargrave and others had developed. Upon that foundation numerous

machines were built and met with varying degrees of success. The principle of vertical and horizontal movable surfaces for control was applied to these box-kite type of aircraft, and in several cases a dihedral angle was used to assist lateral balance; vertical surfaces between the planes also tended to assist lateral stability. Wheeled undercarriages and engines of the adapted automobile type—of which the Antoinette was an outstanding example—were employed, and wing sections which, though often crude, were sufficient for flight with the power available. The only device lacking was that for positive control laterally which the Wright brothers held as their invention and had perfected in their system of wing warping. There is little doubt that the underlying principle had been grasped and its application suggested earlier—there is at least one patent in which the idea was proposed*—but it had not been worked out in practice. Hence the aeroplane, as evolved in Europe, possessed all the essentials save one, and it is unthinkable that for this single exception investigators had to rely wholly on the Wright brothers. They justly claimed the idea as their own because they applied it in a practical way, but, it is argued, the principle of the warping wing (and the aileron) is not so abstruse as to have evaded discovery independently by the pioneers of the aeroplane in Europe. Without detracting in any way from the wonderful achievements of the Wright brothers, it should be recognized that flight was accomplished independently in Europe, and the ultimate perfection of the aeroplane was inevitable there.

The principal constructors and pilots in France during the period under review (1903–1912) were Santos-Dumont, Gabriel and Charles Voisin, Ernest Archdeacon, F. Ferber, Henry Farman,† Léon Delagrange, Esnault-Pelterie and Louis Blériot. Archdeacon had constructed a glider of the Wright type in 1903, and was joined by Gabriel Voisin who collaborated with him in gliding experiments. Later they adopted the box-kite form of structure for gliding, and during 1904 a motorless machine on those lines was tested at Issy-les-Moulineaux, being towed by a motor car, and subsequently, when fitted with floats, over the Seine at Billancourt. Free gliding does not seem to have been undertaken, but the machine constituted the basis for the aeroplanes produced by the Voisin brothers and Henry Farman. The design consisted essentially of two main superposed planes, 5 ft. apart, between which were placed four vertical surfaces or " curtains " intended to assist lateral stability. The tail consisted of a similar but smaller structure placed in the rear, and it contained a vertical rudder; the elevator plane was in front, as in the Wright design, and there was no further control mechanism. Various modifications were made to the design before the application of power in the form of a 50 h.p. Antoinette and other engines, but the essentials remained the same (*see* Plate XXII).

The first Voisin machine was constructed for Léon Delagrange and was tested early in February 1907 but was not at once successful. A second machine was built for Henry Farman, who flew it for a distance of about 90 yds. at Issy-les-Moulineaux during September, and later increased the distance to 843 yds. Farman continued to improve the performances, and on January 13, 1908, he summoned the Commission of the Aero Club of France and succeeded in winning the Deutsch-Archdeacon prize of £2,000 for a circular or triangular flight of 1 kilometre. By accomplishing a circular flight of about

* Matthew Boulton's patent No. 392 of 1868 dealt with a device to exert a righting movement on air-borne surfaces.

† Farman was an Englishman domiciled in France.

1 mile in 1 min. 28 sec. he demonstrated in Europe that the aeroplane was at last a practical machine capable of sustained and controlled flight. The degree of control and the general performance did not equal that already achieved by the Wright brothers in America, but the event marked an outstanding stage in the parallel development in Europe. When on July 6, 1908, Farman established a record in France by remaining in the air for nearly 20 min., the enthusiasm exceeded that of any previous achievement. On April 11 Delagrange had won the Archdeacon Cup by a circular flight of nearly 2·5 miles on his Voisin biplane, and the machine must be recognized as a successful prototype in France; the later Farman biplanes were direct descendants from it.

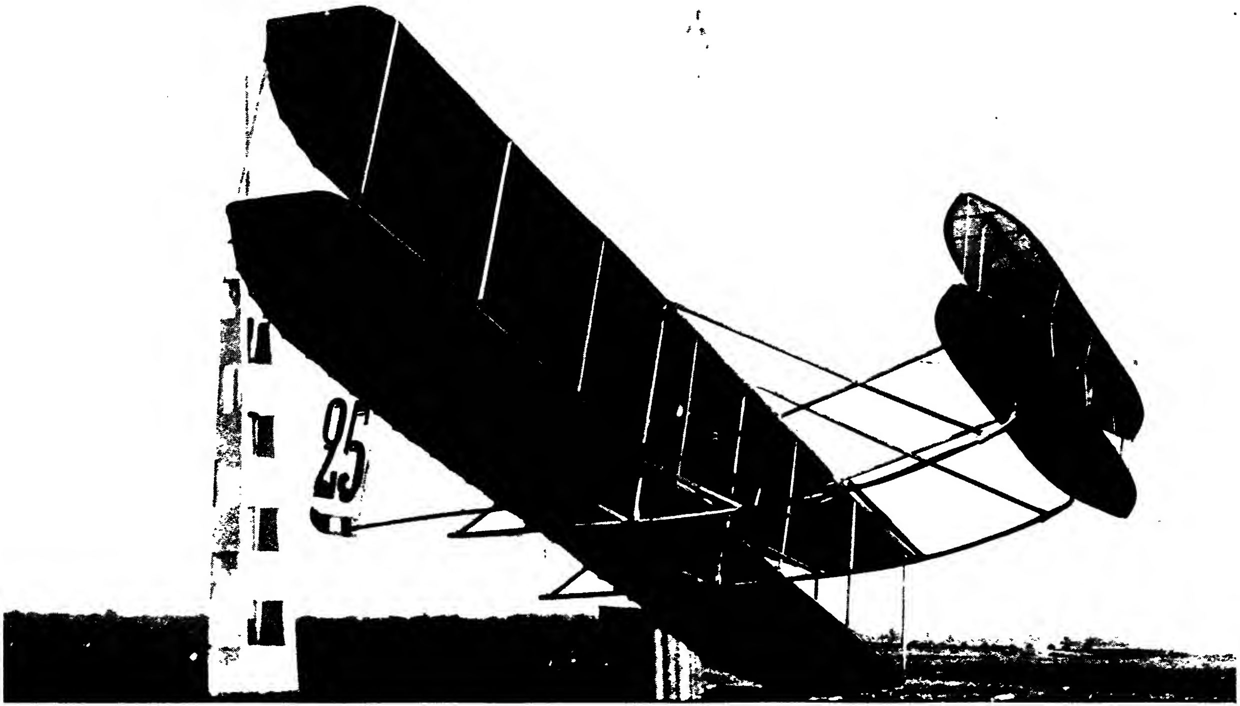
A point of some importance is that the Voisin machines were intended to be automatically stable both longitudinally and laterally, in contrast to the Wright machines which were deliberately designed to be dependent entirely on the the skill of the pilot to maintain stability. Thus there existed two opinions as to how an aeroplane should be kept in equilibrium, and the future trend of development will be observed with interest. The total area of the Voisin biplanes was about 430 sq. ft. as compared with the 510 sq. ft. of the first Wright biplane, but the engine power was much greater, being 50 instead of 12 h.p., and the wing loading about 3·5 lb. per sq. ft. as against 2 lb. per sq. ft. The speed was in consequence greater, and it appears to have been at least 40 m.p.h. in still air, but the first Voisin machine was, on the whole, not so efficient as the Wright brothers' machine of 1903 and much below that reached by them in 1907. To summarize, we may say that the Voisin aeroplane was considerably less efficient than the contemporary Wright aeroplane and it was characteristically different in that it was to a certain extent automatically stable. Later a tendency was apparent to converge to uniformity. The Farman machine, as developed from the Voisin biplane, had flaps, or ailerons, at the rear extremities of the upper plane for lateral control analogous to the Wrights' method of wing warping, and the " curtains " were abolished. An elevator plane was fitted in the rear, and later the front elevator discarded. In the case of the Wright biplane, development resulted ultimately in the transference of the elevator from the front to the rear of the machine, with other modifications, and the use of a wheeled undercarriage.

Emphasis is laid upon both these changes in design because they show that, having started from the two very different standpoints of complete control by the pilot, and of automatic stability, the tendency was to compromise, and by adopting the best features of both to produce aeroplanes of similar characteristics. This may be regarded as the first step towards standardization, but it was some years before there was general acceptance of a design and distinct types emerged. Owing to the large number of experimenters at work during the period 1908–1912 it is impossible to describe here all the different types of aeroplanes constructed and it would not be profitable to attempt to do so. It is said that many of them never succeeded in leaving the ground at all, and one was tempted to speculate on whether they could fly rather than on what their speed, etc., would be. This book is concerned with the outstanding achievements and the main tendencies; it is possible to mention individuals only as representing a trend of thought and not, with one or two exceptions, as personalities. Mechanical flight is now approaching a stage in development where it is desirable to try to see it as a whole rather than as

PLATE XXII

Voisin Biplane in Flight at Rheims, August 24, 1909

An aeroplane based on the cellular or box-kite form of construction, which was largely followed in France during the period 1907-1909. Control was by a front elevator and rudders in the rear; no aileron or wing-warping device was provided. *See Pages* 110, 124



Wright Biplane in Flight at Rheims, August 24, 1909

The Rheims aviation meeting was an event of historic importance, marked by performances which were notable and spectacular. (See Pages 117, 124)

a series of disconnected experiments, and the progress during each of the next four years will be described with that end in view.

1908

The year 1908 was marked in France by the flights of Henry Farman already described; it marks also the appearance in a successful form of another type of aeroplane. The monoplane, as introduced by Louis Blériot (1872-1936) and Robert Esnault-Pelterie, was destined to cause long and sometimes acute controversy as to the relative advantages of the two types—biplane and monoplane. Blériot had designed and constructed his first monoplane in 1907, and had now evolved and adopted means for lateral control in the form of movable planes attached to the extremities of the main planes; this was later replaced by wing deformation or warping. The essential characteristics of the highly successful Blériot monoplanes were an engine in front with tractor airscrew, a long tapered body (fuselage) containing the engine, pilot and fuel tank, and the tail arrangement of horizontal plane with movable extensions (elevators) and the vertical rudder. A two-wheeled undercarriage, with shock-absorbing mechanism and a third wheel in the rear, provided for taking off and landing. Modifications and improvements were made as new machines were produced and the Blériot control mechanism was patented. It consisted of a hand-lever universally jointed and carrying a bell-shaped fitting (the *cloche*) to the edge of which were attached four wires, fore and aft for operating the elevator, and on either side for warping the wings; thus the lever could be used to operate each control separately, or both together in appropriate degree, with one hand. The usual foot bar was used to operate the rudder. It will be appreciated at once that this was a very significant device and actually it marked the inception of the modern control column, colloquially termed the "joystick." Other claims to have originated the device need not be considered here; the essential fact is that of its introduction and successful use. The monoplane of Esnault-Pelterie is of interest because it was constructed largely of metal, and another famous type, the Antoinette, was characterized by very graceful lines.* Santos-Dumont produced a tiny monoplane known as "La Demoiselle," but it was not a type which endured.

In England A. V. Roe (now Sir Alliott Verdon-Roe) was developing a biplane of his own design, to which he fitted a 24 h.p. Antoinette engine. This machine was tested at Brooklands in June and succeeded in rising from the ground for short distances, but, in accordance with the findings of a committee,† it did not accomplish free flight. He was responsible later (1911) for the introduction and development in England of the tractor type of biplane (and also triplane)—a type which endured for over a quarter of a century and proved highly successful. Remarkable work in the development of inherently stable aeroplanes was accomplished by J. W. Dunne, who had begun his investigations in 1904 with small paper models, and he evolved a back-swept wing form of surface which he applied first to monoplane construction.‡ In 1906 Dunne had been engaged by the British War Office

* The only complete Antoinette monoplane now remaining is exhibited in the Science Museum.

† Committee appointed by the Royal aero Club under the chairmanship of Lord Gorell to examine evidence relating to the first flights in Great Britain, 1929.

‡ Mr. J. W. Dunne is probably better known to-day for his work in metaphysics and as author of "The Experiment in Time" and "The Serial Universe."

to design and build a monoplane on the same principle; the machine was tested at Blair Atholl in Scotland under conditions of great secrecy, first as a glider and then as a power-driven machine, when it proved moderately successful with an engine of 20 h.p. His investigation of the subject of inherent (automatic) stability was a brilliant work, the full value of which is probably not even yet realized. He represented that school of thought which was determined to investigate the whole question of stability as exemplified in natural phenomena, and his investigations were not confined to bird flight but embraced leaves, seedpods and other organisms in nature which functioned in action on the resistance of the air. He collaborated also with Professor A. K. Huntington, and later constructed a large biplane which will be described in due course. José Weiss, and Igo Etrich in Central Europe, were experimenting on the same lines, *i.e.* towards the development of a completely self-righting aeroplane which would provide a maximum of safety in flight. Unfortunately it was found that a really high degree of automatic stability generally resulted in loss of efficiency in other ways; speed and ability to manœuvre were sacrificed, and there was also the drawback that the pilot might not be able to exert adequate control when he desired to do so—the tendency was for such machines to go as they were disposed to. For these, and other reasons, the inherentl stable machine has not been intensively developed or widely used, but, from the standpoint of safety and simplicity in control, it may yet offer the means for producing a fool-proof aeroplane.

The essential features of the Dunne machines were the arrangement of the main planes in the form of a V, the apex pointing in the direction of motion, and the absence of any rudder or tail arrangement. Control was effected solely by the operation of flaps, or ailerons, operated by two levers used together as elevators or independently for lateral control. A high degree of natural stability was obtained by the use of the back-swept wing surfaces, the development of which was a highly technical matter, though the principle can be traced in the wings of seabirds when gliding with wings partly flexed.

Another experimenter, who was also attached to the Balloon Section of the Royal Engineers at this time, was Samuel Franklin Cody, an American by birth. He applied his knowledge, gained from experiments with man-lifting kites begun in 1905—a subject in which Major B. F. S. Baden-Powell had also done valuable work—to the construction of a power-driven machine with which he was able to rise from the ground on several occasions in 1908.* The experiments took place over Laffan's Plain at Farnborough. Cody was a romantic figure and his work attracted a good deal of attention in England; his real success came, however, later.

In the United States of America the Wright brothers were continuing to develop their machine in fulfilment of a contract with the War Department for the supply of an aeroplane which would carry a pilot and one passenger for at least ten miles across country at a speed of 40 m.p.h. Wilbur Wright came to France on the invitation of a French syndicate and Orville Wright remained to fulfil the contract. On September 9 he accomplished the first flight exceeding 1 hour in duration (the time being 1 hr. 2 min. 30 sec.) at Fort Meyer, U.S.A., but a few days later he was involved in an accident—the first fatal accident with an aeroplane—when his passenger, Lieutenant Selfridge,

* Cody described this machine as a "power-kite," showing how close was the connexion.

was killed and he himself badly injured. Glenn Curtiss, in collaboration with Alexander Graham Bell, J. A. D. McCurdy and F. W. Baldwin, in the Aerial Experimental Company, produced the "June Bug" with which he gained the first prize offered in America in connexion with mechanical flight and flew a distance of a mile. It was followed later by several very successful machines, and Curtis proved his ability both in design and research.

World interest in aviation became, however, centred in France in 1908. In July Wilbur Wright arrived, and the enthusiasm and stimulus caused by his flights there played an important part in subsequent development and a period of keen competition and rapid progress began. His first flight in France was made at the Hunaudières racecourse at Le Mans on August 8, when he made evolutions in the air in a manner unknown in Europe. During the following weeks the flights were continued at the Camp d'Auvours with increasing duration. The performance made a deep impression; on September 21 he flew for 1 hr. 31 min., covering 55 miles, and on October 4 he carried a passenger for 1 hr. 4 min. 26 sec., and four days later flew with Griffith Brewer, who was thus the first Englishman to travel in an aeroplane in free flight. The Wright aeroplane was criticized for the fact that it required a rail to be used for starting purposes—no wheeled undercarriage having yet been fitted—and was thus said not to be a practical flying machine. In addition, it relied entirely on the skill of the pilot to maintain the proper flying attitude, and that characteristic was undoubtedly responsible for many fatal accidents later, not only with Wright machines but with others having no self-righting properties. These facts did not, however, detract from the remarkable performances which, as already remarked, caused a great stir in Europe and acted as a tremendous incentive to further effort and development.

Henry Farman on his Voisin biplane accomplished the first cross-country flight on October 30 by flying from Châlons to Rheims, a distance of about 17 miles. in 20 min. Blériot on the following day made a circular flight on his monoplane Blériot VIII of about 19 miles, with two descents, and on December 31 Wilbur Wright exceeded all previous achievements by flying for 2 hr. 20 min. 23 sec., covering a distance estimated to be about 93 miles. This was a fitting conclusion to a notable year of progress.

1909

The year 1909 is famous in the history of aeronautics for two events which are important on account of their psychological effects and as evidence of technical progress. One was the crossing of the Channel by Louis Blériot and the other the Rheims aviation meeting—the first of its kind—which was attended by some quarter of a million people. It will be recollected that the Channel was first crossed in a balloon on January 7, 1785, and that it was a very notable adventure. The crossing by aeroplane was of greater significance because it showed that the flying machine was at last a practical vehicle capable of carrying a man from one country across the sea to another. The psychological effect cannot be denied, and though longer flights had been made across country, Blériot's feat has been selected by general consent as a landmark in progress. The conditions under which the competition was organized were calculated also to produce the maximum moral effect and

ultimate recognition of the fact that Britain had lost something of her traditional isolation. It betokened a revolution in human affairs.

In July Hubert Latham, who piloted the Antoinette type of monoplane with great skill, announced his intention to fly the Channel from the French coast and on the 19th made his first attempt, when he unfortunately had to descend in the sea owing to engine failure. On the morning of July 25, Blériot, who had also entered his machine No. XI for the prize of £1,000 offered by the *Daily Mail*, left the French coast at Barraques and descended at Dover a little more than half an hour later. The machine (*see* Plate XXI), which was typical of Blériot's design, had a span of 25·5 ft. and a total surface of 150 sq. ft. with a loading of about 4 lb. per sq. ft. An air-cooled Anzani engine of the " fan " type with three cylinders, stated to develop 22 to 25 h.p., was fitted.* The power was only just sufficient, and it was said that had Blériot not passed through a shower of rain, which helped to cool the engine, he would never have reached the English coast.

The Rheims flying meeting began on August 22 and resulted in some very fine performances being recorded under weather conditions which had hitherto been considered prohibitive. Nearly forty aircraft were present, but all did not fly. The duration record was increased by Henry Farman to 3 hr. 4 min. 56 sec., when a distance of about 112 miles was covered, and a speed record of nearly 50 m.p.h. was created by Glenn Curtiss. The prize for greatest altitude was awarded to Latham, who reached a height of just over 500 ft. It is said that nine machines were in the air at one time, and the impression gained was most stimulating (*see* Plates XXII and XXIII). At this period the petrol engine, as designed for use in aircraft, was being improved and was providing more power for weight with some increase in reliability, but many otherwise fine performances were marred by engine failure. Obviously the development of the aero-engine was essential to progress, reliability being a matter of prime importance, and the performances of the next few years were dependent largely on improvements in engine design. The famous Gnome rotary engine had appeared and superseded the earlier Antionette. It provided a considerable range of power for a very low weight—about 3·5 lb. per h.p.—and ease of fitment, and was applied to many different aeroplanes in France and in England. Unfortunately it suffered from excessive fuel and oil consumption and general unreliability, and was itself superseded a few years later by improved radial and V-type engines.

The distinction of being the first British subject to fly in an aeroplane in the British Isles is accorded to J. T. C. Moore-Brabazon, who during the period April 30-May 2, 1909, made a flight on a Voisin biplane at Leysdown, Isle of Sheppey. Cody succeeded in making flights of several hundred yards, and by fitting a 60 h.p. engine was able to carry a passenger. On September 8 he remained in the air for just over an hour; this was the best performance in England up to date. A. V. Roe constructed and flew a tractor triplane, fitted with a 9 h.p. J.A.P. motor cycle engine, at Lea Marshes during July. The feat was particularly remarkable on account of the low power employed. The brothers Horace and Eustace Short established an aeroplane factory at Shellbeach and manufactured biplanes of the Wright design which were

* The cross-Channel Blériot monoplane is now preserved in the Conservatoire des Arts et Métiers, Paris.

flown later by Alec Ogolvie, F. K. McClean, the Hon. C. S. Rolls and others. They produced also several biplanes of their own design which employed balancing or stabilizing planes at the extremities of the wings—a device adopted also by Cody to take the place of wing warping, which invention was controlled by the Wright brothers. The "Short No. 2" biplane was built for and flown by Moore-Brabazon, and he made a circular flight of a mile with it on October 30—the first mile to be flown on an all-British aeroplane. France was well ahead of Great Britain at this time in development and number of aeroplanes produced. The flight of Henry Farman (who, however, was an Englishman domiciled in France) on November 3, when he flew for 4 hr. 17 min. 53 sec., covering a distance of about 143 miles, is an indication of the rapid progress which had been made there. The Wright brothers had been flying at Pau, in Italy, and in Germany. The first British flying meetings were held at Doncaster (October 15-23) and at Blackpool (October 18-23).

1910

The year 1910 was one of greater activity in England. Flying meetings were held at Wolverhampton, Bournemouth and again at Blackpool. A prize offered by the *Daily Mail* for the first flight from London to Manchester, within a time limit of 24 hours and with not more than two stops, was won by the French pilot Louis Paulhan on April 27-28. Claude Grahame-White, who had made an attempt earlier and had the misfortune to have his machine damaged at night when left in the open, started in pursuit, but engine failure spoilt his chances. It was a most thrilling contest and one of those events which, like Blériot's crossing of the Channel, has become definitely historic, more because it captured public imagination than because it represented any evidence of great technical advance. The first pilot's certificate issued in England had been granted to Moore-Brabazon on March 8, and flying took place mainly at Brooklands, at Hendon and at Eastchurch in the Isle of Sheppey. The Bournemouth meeting, which began on July 10, resulted in marked improvement on the records established at Rheims. The altitude record was increased to 4,107 ft. and the speed record to 56·64 m.p.h., while Grahame-White succeeded in climbing to 1,000 ft. in 6 min. 36·8 sec. He also made an interesting experiment at Blackpool in carrying letters by air. In the United States of America, Curtiss made a remarkable flight of nearly 3 hours' duration from Albany to New York.

The first flight of an aeroplane fitted with floats to ascend from and alight on water took place on March 28, the machine having been constructed by Henri Fabre during the previous year. An important patent was granted in Germany to Hugo Junkers (1859–1935) for an "all-wing aeroplane"—a most significant conception in which the engines and passenger accommodation were to be contained in a single thick wing—and the general principles underlying it governed much of his later work in the development of all-metal machines and may be traced in the almost universal practice to-day. This was undoubtedly the most profound technical advance made during 1910, and though it did not materialize for some years, the inception of the idea is of great historic importance.

1911

The year 1911 saw further increases in the records for duration, speed and altitude, providing evidence of the steady improvement in the design of both aircraft and engines which was taking place. In England A. V. Roe introduced the tractor biplane, which proved to be a most successful type and led to the production, during 1912, of the famous Avro model 504 by the firm of A. V. Roe & Co., Ltd. The inception of the tractor biplane was a notable event in the history of development because it was a type which became standardized and has endured to the present day. In America development of the seaplane was undertaken by Glenn Curtiss, and we find that taking off from and landing on the deck of a ship had been successfully accomplished by Lieutenant Eugene Ely of the United States Navy; these appear to have been the first experiments of their kind, from which the idea of the aircraft carrier developed. In France the production by Edouard Nieuport of monoplanes—the original design dating from 1909—in which wasteful resistance was much reduced by the use of a large fuselage of good streamline form, in which the pilot and passenger were almost wholly enclosed, was significant. Developments in detail were so numerous and varied that it is impossible to describe them here. We are approaching the time (1912) when the aeroplane achieved some degree of standardization, and it will be more profitable to postpone any detailed description until that fairly well defined stage is reached. The year of 1911 may be regarded as one of transition, when aviation was passing rapidly from being merely a sport for the adventurous to being a new and potentially powerful means of transport and weapon of offence. Unorthodox—we may even call them freakish—designs began to be replaced by machines based on sound, if elementary, aerodynamics, and the question of safety was receiving more attention. As in the case of the balloon, safety was a factor which had, unhappily, been overestimated and the occurrence of fatal accidents had a damaging effect on progress.

In January 1911 France had 353 certified pilots and Great Britain 57. Germany had 46, Italy 32, Belgium 27 and the United States of America (where flight was first accomplished) only 26, but by the end of the year the latter figure had been increased to 82. These figures give a fair indication of the extent of aviation in a comparative sense, but the more remarkable flights of the year show most vividly how far air transport had progressed.

On April 12 the French pilot Prier flew non-stop from London to Paris, covering about 250 miles in a little under 4 hours. In May a Paris–Rome–Turin race was won by Lieutenant de Conneau in a total time of 82 hr. 5 min., but his flight involved a change of engine *en route*. A circuit of England from London was also won by de Conneau. These cross-country flights involved frequent stops and often more or less elaborate repairs and overhauls were made. Two events of a different character are now definitely historic. On September 9 a tentative air mail service was begun between Hendon (London) and Windsor, but was soon withdrawn. In the United States of America a similar trial at carrying mails was made during September. It has been stated that there were some 300 aeroplanes actually usable in America at this time and the number in France was considerably more. The world duration record stood at just over 13 hours, the altitude record at 13,000 ft. and the distance record at 459 miles. At the third aeronautical exhibition held in

Paris (December 1911) twenty-eight different types of aeroplanes were exhibited. At Kitty Hawk, North Carolina, Orville Wright accomplished a soaring flight of 9 min. 45 sec. in a motorless machine.

1912

In the history of flight the year 1912 is marked by a great loss and also by proof of great gain. Wilbur Wright, who was never robust, died on May 30 at the early age of forty-five years, and, as though his work had been completed, there was evidence then that the first real stage in the development of the aeroplane had been reached. By his death the world was deprived of a remarkable and original personality, and the science of mechanical flight of the pioneer to whom, jointly with his brother Orville, it owed much of its rapid development.

Educated in the high schools of Richmond, Indiana, and Dayton, Ohio, Wilbur Wright had passed with his brother from comparative obscurity through discouragement to ultimate success and fame. He appears to have been denied the advantages of a purely technical training, but as it has been said of Faraday that without mathematical training he thought mathematically, so it would seem that Wilbur Wright possessed that acuteness of perception which extracts the essential lesson from experience and instinctively constructs a system of coherent thought. The genius that begins at the beginning and builds up by conscientious study of elementary points—which many hastily assume they understand—is well exemplified in his character. In addition, he and his brother possessed a remarkable aptitude for supplementing each other's efforts, and it was that unity of purpose and perfect understanding which brought them success. It has been said that no one could forecast what Wilbur Wright would do in any particular circumstances; the only thing that one could count on was the truth of any positive statement that he made. He had a singularly attractive personality with a lean and bird-like face which gave the impression of an ascetic and refined recluse. His love of solitude and simplicity led him to shun crowds, and his mind was too full of technical problems to concern itself with the spectacular side of his experiments. He was wholly indifferent to everything of a showy nature; neither the impatience of waiting crowds, nor the sneers of rivals, nor the pressure of financial conditions—not always easy—could induce him to hurry over any difficulty before he had done everything in his power to understand and overcome it. From the beginning to the end he pursued his research patiently and dispassionately.

The achievement of Wilbur and Orville Wright was the triumph of a blend of qualities, moral and intellectual, which permanently secures for them the foremost place in the history of aeronautics.

* * * * * *

The stage in the development of the aeroplane reached in 1912 is not easy to define in a few words, but it was nevertheless definite. Essentially it was the approach to a settled form in aeroplane construction so that it was becoming possible for a designer to forecast, with some promise of accuracy,

the performance of a machine before it was built. The aeroplane had not advanced sufficiently in any country to be a commercial asset, and, though its value in naval and military operations was beginning to be realized, there existed then no considerable demand for flying machines for that purpose—the first machine to be designed and definitely equipped in Great Britain for military use, the Vickers Fighter or " Gun-bus," was not produced until 1914. Nevertheless, the broad lines on which future development was to be based were laid down, and there emerged from the chaos of the early experimental work some order and agreement in regard to methods of design. In England the tractor type of biplane was intensively developed and there appeared the famous Avro machine model 504 already referred to, which represented a very high standard in design, and the type was in use for civil, military and training purposes practically unaltered for over fifteen years. Examples of the machine are, even to-day, in use and are evidence of the excellence in design which marks the year 1912 as the beginning of standardization. The Royal Aircraft Factory at Farnborough produced the first successful biplane designed and constructed under official auspices. This biplane, the B.E.2 (Blériot Type Experimental No. 2), was constructed from the design of Geoffrey de Havilland, being developed by E. T. Busk, and it was adopted as a standard machine for the British Royal Flying Corps. It was intended to combine all the features desirable in a military aeroplane and in all-round efficiency it probably surpassed contemporary machines. A British height record of 10,500 ft. was made during August, and later, the type was developed to incorporate a fair degree of automatic stability and the performances in general were improved. In France the monoplane found greater favour, as also in Germany and other parts of Central Europe, where the type evolved by Etrich and Wels, which embodied a degree of inherent stability, was used largely for civil and also for military purposes. An obvious advantage of the tractor type (monoplane and biplane) was that it facilitated the construction of a totally enclosed body, or fuselage, of good streamline form and this was well illustrated by the cabin monoplane produced by A. V. Roe & Co., Ltd., and the French Deperdussin monoplane which avoided external fittings calculated to impede progress through the air. In France, however, the early form of biplane with engine and airscrew in the rear was still produced in large numbers, particularly by Henry and Maurice Farman. Of these the most famous were the Maurice Farman " Longhorn " and " Shorthorn," the former having a front elevator with projecting structure which invited the analogy in the animal world. These machines were invaluable for training purposes, for which they were largely used, and they will, with the Avro biplane, be familiar to many of those who learned to fly during the period 1912 to 1918.

Considerable progress was made in seaplane construction and an important meeting was held at Monaco during March, when Farman, Curtiss, Caudron, Voisin and other machines took part. Curtiss seaplanes were supplied to the United States and Russian Governments, and the Admiralty commissioned H.M.S. *Hibernia* as a seaplane carrier. Experiments were undertaken with machines which represented a radical departure from the then (and now) accepted practice. Of these, one of the most interesting was probably the annular monoplane developed in England by G. Tilghman Richards and Cedric Lee during the period 1910 to 1914.

It is recorded that by July 1, 1912, 155 men and 3 women had lost their lives in aeroplane accidents, and though it is not easy to estimate the full moral effect of these fatalities, it is certain that they were harmful to the development of mechanical flight if only because of their influence in regard to the withholding of financial support which was essential to make the aeroplane successful commercially.

The world aeroplane records at the close of 1912 were: duration, 13 hr. 17 min. 57 sec.; altitude, 18,406 ft.; speed, 108·2 m.p.h.; distance (non-stop), 633·1 miles.* These records serve as an indication of the progress which had been made, though they cannot of course be accepted as evidence of normal performances.

An event of some significance, in view of subsequent history, took place in England during the autumn of 1912. The opposing forces in the Army manœuvres were each provided with eight aeroplanes of the Royal Flying Corps (one squadron) for the purpose of reconnaissance, and Cody was one of those who took part. The full results of the experiment were not made known at the time, but it is recorded that when flying over Cambridge he was able to give such information regarding the disposition of the forces that the plan of campaign was materially altered, and it appears that the value of the aeroplane for observation in warfare was demonstrated for the first time—at least in this country.† Air reconnaissance on that occasion resulted in the manœuvres being brought practically to a standstill by reason of the fact that each side was made aware of the disposition of the other, and it was a foretaste of the situation during the Great War (1914 1918) when the opposing forces were similarly immobilized.

The full military importance of flight was not, however, immediately realized, for, even in 1914, there was a disinclination in the minds of some highly placed commanders to believe in (or to admit) the possible uses of the aeroplane in war. Aircraft had been used by Italian forces to attack Arab formations in Tripoli in 1911 and, later, for reconnaissance; but the lesson was generally ignored and conservate elements continued to regard cavalry as irreplaceable for that purpose. It has been suggested that the battle of Waterloo would not have been won had Napoleon possessed even a single flying machine for reconnaissance and—apart from such speculation—the conviction that aircraft would revolutionize war was surely not an idle one.

* As given in the *Bulletin* of the Fédération Aéronautique Internationale.

† The machine used, which was facetiously known as " Cody's Cathedral " on account of the elaborate and clumsy appearance, is preserved in the Science Museum.

XI. DEVELOPMENT OF THE AEROPLANE IN PEACE AND WAR

1912–1919

FROM THE STANDPOINT OF TO-DAY, the year 1912 marks the beginning of a quarter of a century's development. It is a convenient period over which to look back and to compare the status of the aeroplane as it was then and as it is now. In 1912 some degree of standardization had been reached and the flying machine was generally regarded as a proved instrument, and rightly so, because its improvement had been rapid and effective. But progress during the next two years did not proceed as quickly as might have been expected, for the aeroplane had not advanced sufficiently to be regarded as a commercial asset, and the demand for naval and military purposes was inconsiderable. No government would have contemplated an expenditure of millions of pounds annually on air power, or even a much smaller sum as a subsidy to commercial air transport. The position was one of uncertainty as to the future use and development of the aeroplane. Some special stimulus was required if the rate of progress in design and use was to be accelerated, and, as everyone knows, the war of 1914–1918 provided an incentive, for from a tentative and untried military device, the aeroplane was developed into a highly scientific weapon which was of vital importance to the countries concerned.

It is not suggested that war was the only possible stimulus for increasing research and production, or that it was the best incentive, but the fact remains that it had a profound effect on the development of mechanical flight, and it is difficult to see how a similar result could have been produced without it. By a curious perversity, the intensive development of the aeroplane (and of the airship also) for destructive purposes has been of great benefit in other and more proper spheres of operation. Had, however, the expenditure devoted to perfecting the aeroplane for offensive and defensive purposes in various countries been used for developing it on more normal lines for efficient air transport, then there is no doubt that the gain would have been very much greater. Moreover, we cannot escape from the conclusion that the intensive development of a war period conducted under conditions of some secrecy is not economically sound, and when there is no sharing of the results of research—except perhaps between allies—progress is retarded.

The years preceding the 1914–18 war were marked by increasing competition in armaments and the conditions were favourable to competition in air power as well when the situation demanded it. Under these circumstances the rapidity with which the aeroplane was developed in the face of necessity, and with the financial support which a state of war provided, is easily understandable; it was a period of forced and intensive action which probably has no exact counterpart in the history of any other branch of technology. The cost was a factor which must, however, be taken into account; it represented much of the difference which exists between competition and that co-operation which is so desirable in scientific research and technical development. If,

prior to 1914, there had been the vision to seek, and the will to secure, international agreement to obviate the use of aircraft for military purposes, the position would have been very different and development in aeronautics would probably have been at a standstill during the succeeding years of war.* The ultimate advantages of such an agreement—had it been possible—would have far outweighed the loss of four years of intensive development, and the aeroplane would have emerged free from abnormal influences and could have evolved quietly and efficiently with the sole object of fulfilling its purpose as a great instrument of communication.

It has been seen that the speed record in 1912 slightly exceeded 100 m.p.h., and this factor of speed was a very important one because, apart from its being the most distinguishing characteristic of the aeroplane, it was the factor which largely determined the value for military purposes. The problem was to obtain a high speed in a machine which was suitable in other respects for military use. Early in 1913 an opinion was expressed in this country that a single-seater aeroplane for scouting purposes with a speed of 90 m.p.h. and a landing speed of 45 m.p.h. would be ideal. and the modest estimate serves to show that the higher performances indicated in the various records were not then regarded as practicable in ordinary use.

At the aeronautical exhibition held in London during March 1913 the Vickers two-seater military biplane, designed specially for that purpose, was shown; it had a speed of 65 to 70 m.p.h. The tractor biplane designed and produced by T. O. M. Sopwith was capable of 80 m.p.h. with a landing speed of as little as 30 m.p.h.; a British altitude record of 13,000 ft. was made on a Sopwith machine in June 1913. Performances of military aircraft in other countries were little, if at all, in excess of these. At that time the practice of wing warping for lateral stability, originated by the Wright brothers, was beginning to die out and most aeroplanes were fitted with flaps or ailerons which embodied the same principle, but were more practical because the continued deformation of the wing itself tended to stretch the fabric. The fact that it was possible to obtain greater efficiency, and in particular higher speed, from machines with the airscrew in front than in the rear was beginning to be realized, and in consequence the " pusher " type was largely superseded. It was found possible to reduce wasteful resistance to a greater extent in tractor machines by the use of a streamline fuselage, or body, which connected the main planes with the tail. Against this was the difficulty of operating a machine gun in a forward direction on account of the revolving airscrew, but this was met by the use of deflector plates introduced by Morane in 1915 and intended to prevent damage to the airscrew, and later was overcome by an ingenious device, known as " interrupter gear," which permitted the gun to fire only when none of the airscrew blades was passing in front of the muzzle.

In England the tractor biplane was most favoured, the Sopwith and Avro types being the leading machines of their kind in the world. Both were two-seaters with a speed of from about 40 to 90 m.p.h. with engines of nominally 80 h.p. In France the tractor monoplane continued to find more favour and

* Actually, the Hague Peace Conference of 1899 placed on record that aircraft would not, by international law, be permitted to take a combatant part in war, and the discharge of projectiles or explosives from the air was prohibited. During the Conference of 1907, however, when the airship was well established and the aeroplane becoming practical, the statement was much less positive.

the Gordon-Bennett race in September 1913 was won again by such a machine—a Deperdussin monoplane—which was developed to give a speed of 126 m.p.h. by increasing wing-loading. This machine had a span of only 21 ft. with a chord of 5 ft., which gave the small aspect ratio of approximately 4 to 1 and a supporting area of only just over 100 sq. ft., the total weight being about 1,500 lb. The resulting high wing-loading (nearly 15 lb. per sq. ft.) had previously been unthought of, but it enabled the high speed to be attained though the very long run necessary on taking off and landing (stated to be nearly a mile) made the machine unsuitable for ordinary use. Obviously the requirement was a wider range of speed so that a machine could land at 40 to 50 m.p.h. and still retain the ability to cruise at high speeds and be generally efficient. Much of the research and development of the war period was directed—as it is to-day—to that end.

In Germany both monoplanes and biplanes of the "Taube" type were developed; these machines embodied a certain degree of inherent stability by means of swept back wings and upturned wing-tips, which resulted in some sacrifice in response and performance. Progress was, however, rapid during the next two years, and it has been stated* that in 1914 Germany possessed no less than 1,000 government aircraft and 450 owned privately. According to the same source, France possessed 1,500 service machines and there were 500 privately owned, but these figures should be accepted with reserve. Great Britain possessed some 300 service machines of all sorts by the end of 1914,† and it is illuminating to note that no less than 22,647 service aircraft of all types were on charge to the Royal Air Force on November 30, 1918.‡ The figures give some idea of the value placed upon aircraft for military purposes as the result of the experience of the war—a value which had been foreseen by some but was not generally realized until hostilities broke out—and it is easy to understand the dominating influence which the aeroplane exerted even at that comparatively early stage in its history. It was used at first for reconnaissance, which was its prime military purpose, and for observation for artillery fire, photography and map making. Later, as was inevitable it was employed for active combatant purposes, such as bombing enemy fortifications, places of strategic importance and even civil populations; machine-gun firing on enemy troops and attacking opposing aircraft. In fact all the uses which, it had been piously hoped, would not be permitted by international law.

We are concerned now more with the effect which the war had on the development of the aeroplane than with the effect which the aeroplane had on the technique of warfare; the latter is, of course, of profound importance in regard to the social significance of flight and it will be referred to in the last chapter. For military purposes the aeroplane was required to have a high speed and rate of climb and an increased manœuvre. Speed became of chief importance, but ability to manœuvre and perform evolutions in aerial combat was also essential. The suitability of a machine for observation, reconnaissance and aerial gunnery depended also on the form of the design, which might assist the performance of those duties or impede by providing insufficient field of view for pilot or observer. The airscrew-propelled, or

* "A History of Aircraft," by F. A. Magoun and E. Hodgins, 1931.

† This figure is based on those given in "The War in the Air," Vols. I and III, the British official history of the war.

‡ "A Short History of the R.A.F.," Air Publication 125, September, 1929.

so-called "pusher" type, which provided an almost ideal field of fire in a forward direction, was sensibly slower and less handy to manœuvre than the tractor-airscrew type. Consequently the latter, with fixed gun (or guns) synchronized to fire between the blades of the airscrew, was ultimately almost universally adopted, but it postulated that the whole aircraft had to be aimed at the target (*see* Plate XXIV). In two-seater machines a movable gun was usually mounted in the rear cockpit, occupied by the observer. and was used for offensive broadside or rearward defensive fire. The rear cockpit was also used to accommodate equipment for observation, photography and wireless communication.

The military aeroplane with its equipment thus became a complicated and highly specialized machine, and a tendency was soon apparent to develop it on lines which did not always make for efficiency in a technical or economic sense. For instance, the demand for increased speed was met by the installation of engines of higher power rather than by any marked improvement in aerodynamic efficiency, though, it is true, the development of better aerofoil sections played a part. Increased factors of safety, due to the use of better materials with appropriate lightening of the structure, together with a further appreciation of the stresses caused by rapid manœuvres in flight, enabled machines to be constructed which were more airworthy than their predecessors of the pre-war period. The development of the war period in this country has sometimes been criticized on the grounds that it actually retarded true progress by concentrating on the improvement of existing methods of design rather than the introduction of new ones, and this in spite of the fact that valuable knowledge was gained concerning the strength of materials as a result of research undertaken purely for aeronautical purposes, research for which funds were made available in the national emergency. The criticism might apply equally to the development in any of the countries at war; the improvement of existing designs was the most prudent course in view of the urgency of the situation. The research undertaken embraced the whole field of aerodynamics, the structural design of aircraft and the stresses involved in all the various conditions of use. Improved wing sections were found, and in British machines one or other of those evolved at the Royal Aircraft Factory was generally adopted. In France, and in Germany particularly, a tendency was apparent to use thicker wing sections, but the conventional ones preponderated.

It has already been remarked that the increased performances of the war period were accomplished largely by the use of higher power engines. Previously to 1914 the problem had been mainly one of simple weight reduction in the power unit; now, the increased range of flight and the losses of aircraft through engine failure demanded greater reliability, ease of maintenance and accessibility with a further improvement in weight to power ratio without sacrifice of strength—in fact all the qualities which are in evidence to-day. The average weight of engines of the air-cooled type, without accessories, was 4 lb. per h.p. in 1914 and this was reduced to 1·9 lb. per h.p. by 1919. Similarly, the water-cooled type was reduced from 4·05 lb. to 2·2 lb. per h.p.*

This was a very remarkable achievement, and it is fairly evident that the development of the aero engine was more rapid than the development of the aeroplane itself during the period under review. The early history shows

* These figures are calculated from the mean of published figures.

that the opposite was then the case; for years the aeroplane waited for the engine—now the reverse tendency was apparent. In 1914 the average maximum height attainable—the "ceiling"—was only some 7,000 ft.; by 1919 this had been increased to 30,000 ft., due mainly to improved engine design. This was even more remarkable in view of the fact that the decreased density of the air with increased altitude diminishes the power that the engine can develop without supercharging—a system which was introduced later. The power loss at 15,000 ft. is, without supercharging, approximately 45 per cent. of that given at ground level, so that the very considerable increase in height attained shows that a remarkable development had taken place. Long-range bombing and reconnaissance brought out the importance of low fuel consumption, which required a close study of thermal efficiency in conjunction with the weight to power ratio, leading to increased engine speeds, while at the same time aerodynamic requirements called for lower airscrew speeds so that ultimately reduction gearing was introduced in some types of engines to obtain greater efficiency. In 1914 this country depended largely on other countries for the supply of aero engines, particularly France whose Gnome and Le Rhône engines were much in use. Great efforts were made to extend the sources of supply, and at the close of the war period Great Britain had gained a high place in design and was also well equipped for the supply of all the engines required. There is no doubt a good deal to be said for a policy which takes advantage of all experience and uses it to the best advantage.

At the beginning of the war Germany and France had, as already noted, considerable numbers of aircraft available for immediate use, those of the former country being, for that period, well adapted for military purposes, while the British Empire had only a small nucleus of machines and personnel available with a very limited number of aircraft manufacturers and no considerable body of instructed talent which could be diverted to aeroplane construction. The aircraft and personnel were so few in number that, at first, all sorts of duties had to be undertaken by each machine. Consistent reconnaissance was impossible and seaplanes were not then sufficiently developed to engage with land machines with any success, their speed, climb and rapidity of manœuvre being much less than those of the latter. The prevalence of westerly winds on the Western Front, which made slow machines particularly susceptible to attack when returning to their own territory, and also the restricted landing-grounds, situated often at some distance behind the front, all forced an extension of the range and speed of aircraft. These were some of the reasons for development, but there were many others, and it is necessary to trace the operations of the British air forces and those of other countries during the war in order to appreciate all that was involved. It is, unfortunately, beyond the scope of this book to describe those operations or to give any really detailed account of the technical development of the period, and the reader must be referred to the volumes of the British official history—"The War in the Air"—which is based on official documents and was prepared by the direction of the historical section of the Committee for Imperial Defence.*

In 1914 the aeroplanes available and in use by British forces were the B.E.2 and the B.E.2c biplanes, the Avro type 504, the Sopwith "Tabloid,"

* The reader is also referred to the survey included in the "Histoire de Aéronautique," by Charles Dollfus and Henri Bouché, Paris, 1932.

some French—and also British built—Blériot monoplanes, and Henry and Maurice Farman biplanes*. A number of machines were still in an experimental stage; they included the R.E.5, a tractor two-seater bomber, the F.E.2, (Farman type Experimental No. 2), a biplane with airscrew in the rear, the S.E.2 (Scouting Type Experimental No. 2), and the Vickers fighter. The production of such firms as the Aircraft Manufacturing Company, Short Brothers, Armstrong-Whitworth, Beardmore, Gloster, Westland, Handley-Page and other leading constructors were soon available. The principal engines in use were the 70 h.p. Renault, the 50 and 80 h.p. Gnome and the 100 h.p. Gnome Monosoupape, all of French design. The R.A.F. type engines—which were generally similar to the Renault—were in process of design at the Royal Aircraft Factory, Farnborough. The B.E.2 (Blériot Type Experimental No. 2) was generally considered to be the best aeroplane available in this country at the outbreak of war. It was designed for reconnaissance, had a fair degree of inherent stability, and gave the observer a good view. The R.E. type (Reconnaissance Experimental) had a higher degree of inherent stability—a subject which had been investigated in England by Dr. F. W. Lanchester, who published, as early as 1907†, his classic exposition of flight based on the vortex or circulation theory of sustentation—a conception received in part with scepticism until proved to have been founded on correct premises by the later work of Professor Prandtl at Göttingen. Professor G. H. Bryan had also investigated the subject in 1911. In the case of the B.E. type, inherent stability was obtained by the careful design of each part of the machine with due regard to other parts and their relationship. The weights and areas were skilfully arranged so that, under most flying conditions, the machine tended to right itself, and if the engine was switched off at a height exceeding 1,000 ft., it would assume its correct gliding angle. This trend in design was significant and emphasis is laid upon it here because, in the author's opinion, it marks a very definite stage in development. It resulted largely from the experimental work of Edward T. Busk at the Royal Aircraft Factory—then under the direction of Mervyn O'Gorman—which followed the research of Professor Bairstow and others in this country.

The reliability and excellent performance of the B.E.2 type was demonstrated in many notable flights. Perhaps the most remarkable was that of Captain C. A. H. Longcroft, who on November 22, 1913, flew non-stop, with Colonel F. H. Sykes as passenger, from Montrose to Farnborough and thence to Portsmouth and back to Farnborough—a distance of about 630 miles at an average speed of over 80 m.p.h.

By 1914 the standard of flying had already very much improved. It is recorded that the first " loop " in an aeroplane was performed by the Russian officer Nesterov on a Nieuport machine in 1913, and during the same year Adolphe Pégoud executed it repeatedly in France and in England, being thus credited with the first public demonstration of aerobatics. The value of these and other demonstrations lay in the fact that they showed the possibility of recovering from any position in the air providing the aeroplane was at a

* These and many other machines are represented in the National Aeronautical Collection at the Science Museum and descriptions of them are contained in the official handbook to the Collections—" Heavier-than-Air Aircraft."

† Lanchester first propounded his theory in a paper read to the Birmingham Natural History and Philosophical Society in 1894 when he was twenty-six years of age. His great work on " Aerial Flight "—" Aerodynamics," 1907, and " Aerodonetics," 1908—followed.

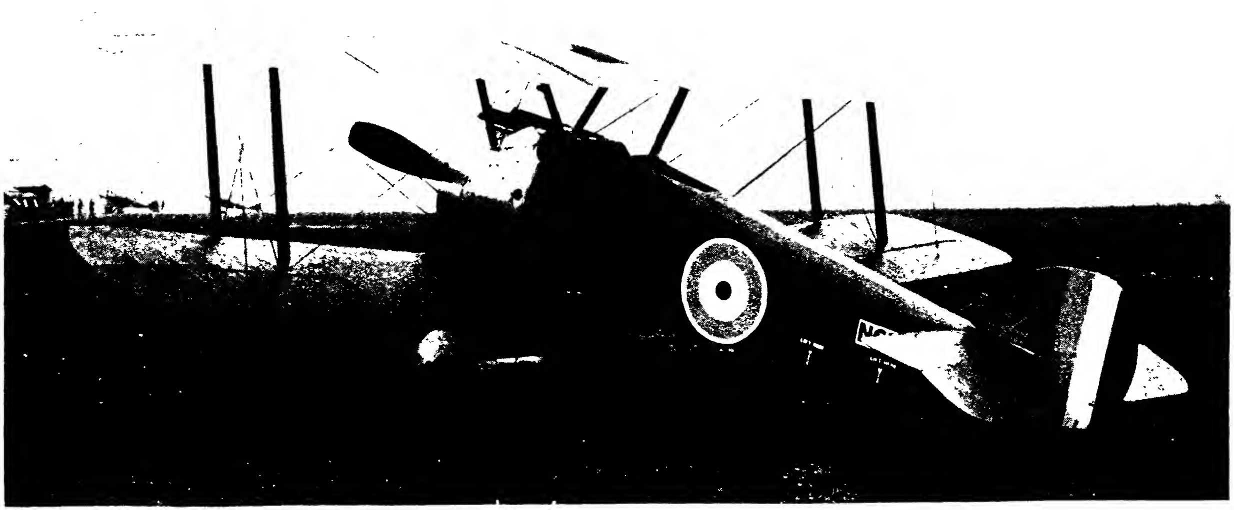
reasonable height, and they resulted in consideration of the abnormal stresses to which a machine might be subjected, and, ultimately, in steps being taken to increase strength where necessary. The machines of the later war period were, as already remarked, required to perform certain evolutions as a part of their normal performance in aerial warfare, and in consequence higher factors of safety were called for and the theory and practice of aeroplane design advanced accordingly, so that it approached more rapidly to become an exact science. There was a corresponding advance in the technique of piloting, though the practice of hurried training necessary to rapid expansion tended to nullify it. The war produced a large number of pilots in various countries—men who would otherwise probably never have flown—and it added much to the then forming tradition of airmanship. A certain chivalry was apparent among the pilots of the opposing forces which appeared in happy relief to the general conduct of war, and it may be regarded as contributing to that solidarity which is evident among airmen all over the world to-day.

During the early part of the war the French air forces used such machines as the Breguet, Caudron and Voisin biplanes with the partially standardized Henry and Maurice Farman biplanes and the Morane-Saulnier, Deperdussin, Borel, Nieuport and Blériot monoplanes. The German forces had available a quantity of biplanes of the Etrich " Taube " type—which, as already noted, were based on inherently stable wing forms—such as the Aviatik, D.F.W., A.E.G., Albatross, Gotha, L.V.G. and Rumpler, and later the light and fast monoplanes constructed by the Dutch designer A. H. G. Fokker. The German machines were designed to use the standardized straight-line, six-cylinder engines produced by Mercédès, Benz, etc., but a few employed the " Oberürsel " or German Gnome engine. There was thus a similarity in German aircraft design which was not apparent in the British and French machines, which were produced to use any type of engine which became available in sufficient quantities. Germany, being subject to blockade, was forced to rely on her own industry, which was developed by organization and discipline to cope with the demand for aircraft.

As the war proceeded resources in all belligerent countries were increased, and additions were made to the lists of constructors. By the end of 1915 the supply of seaplanes in this country was sufficient to warrant the use of seaplane-carrying ships for transporting the machines and personnel of the Royal Naval Air Service, and the aircraft were used for directing the gunfire from ships operating against land emplacements. The range and seaworthiness of seaplanes having rapidly increased, they were also used for action against submarines. By 1916 the average speed of aircraft had risen from 70–80 m.p.h. (in 1914) to 110–120 m.p.h., and by the end of 1917 to 124—135 m.p.h., with a corresponding increase in rate of climb, increase in speed at high altitudes and in maximum height attainable. In 1918 fighter aircraft were in use with speeds of 140–155 m.p.h., so it will be appreciated that a considerable advance had been made during those four years. In 1948 aircraft of the same class attained speeds approaching 600 m.p.h.

Aerial combat and other operations were carried out at altitudes of from 20,000 to 24,000 ft. and those conditions called for the provision of an additional supply of oxygen, the average pilot feeling the effects of rarefied atmosphere at about 18,000 ft. Parachutes were in common use with kite balloons, but

PLATE XXIV



Sopwith "Camel" Biplane, 1917

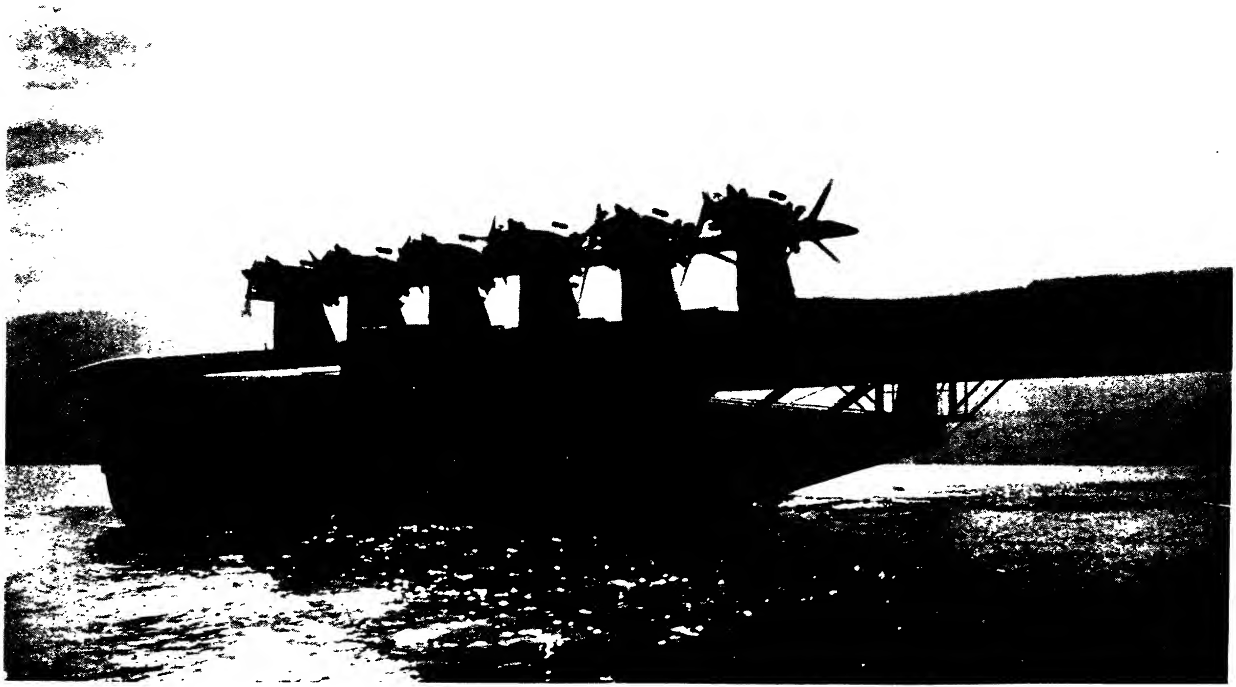
A highly successful military aircraft of the war period, designed for scouting and general offensive purposes. Two synchronized machine guns were arranged to fire through the path of the airscrew. See Page 133

PLATE XXV

The Vickers-Vimy Aeroplane which made the first non-stop flight across the Atlantic, June 14-15, 1919

It covered the distance of 1,800 miles from St. John's (Newfoundland) to Clifden (Co. Galway, Irish Free State) at an average speed of 118.5 miles an hour. (See Page 142)

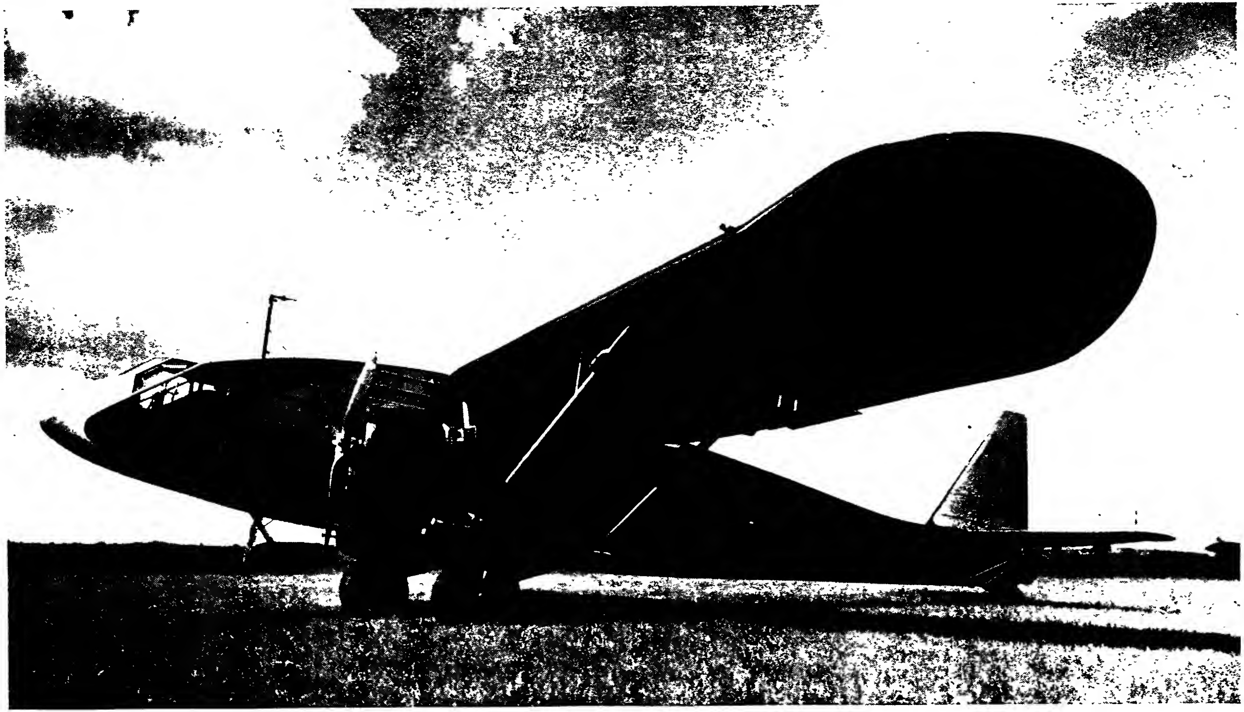
PLATE XXVI



Dornier Do. X Flying Boat, 1929

The largest aeroplane of its time. Having twelve engines each of 525 h.p. and carrying 100 persons; on one occasion it carried 169 persons. See p. 140

PLATE XXVII



Potez Commercial Aircraft Type 62 1936

A fourteen seater air liner with two Gnome-Rhone geared and supercharged engines. Employed by Air France on the Paris-Marseilles and Paris-Scandinavia services, 1935-1936. *See Page* [illegible]

they had not been developed to a state satisfactory for general use from aeroplanes, though they were employed to a limited extent—chiefly in Germany—and it was not until the post-war period that they became almost universal on service machines.

In 1918 two further specialized uses for aircraft were developed, *i.e.* the employment of fast, low-flying aeroplanes against troops on the ground—generally described as " low offensive patrol "—and the establishment of the Independent Force, R.A.F., for continuous bomb-dropping behind the enemy lines. The latter—which represented organization for specialized work rather than a new function—required heavy, load-carrying aircraft which were lightly armed and protected by escorts of fighting scouts. Among British machines designed for this purpose were the D.H.9 and D.H.10 types, the Handley-Page O/400 and V/1500 types. The German forces employed the Gotha, Friedrichshafen and other bomber types for the same purpose, the former in particular being used in raids over London.

It is not easy to summarize the results of the war-period development. As already remarked, a great deal of research was undertaken to improve wing sections both in this country and abroad, and the design of all components received considerable attention. The research carried out made available a mass of data which was almost entirely concerned with improvement in the efficiency of aircraft using aerofoils of various sections and considerable aspect ratio. Great improvement was made in the ratio of " lift " to " drag " but no marked progress was made in controlling the movement of the centre of pressure and there appeared nothing appreciably better than the accepted method of design. Similarly, no improvement on the system of dihedral setting of planes with manually operated ailerons for lateral control was achieved, and the accumulated experience tended rather to discourage research on unorthodox lines, improved performances being accomplished mainly by reduction of structural weight and still higher engine power. It was thus the skill of the engineer and engine designer rather than that of the specialist in aerodynamics which effected the progress during the war period. Perhaps the greatest single advance in design was the introduction by Professor Junkers in Germany in 1916 of the cantilever system of deep-section wing structure—the original patent for which has already been referred to on p 125—together with his typical system of all-metal construction. Metal construction for aircraft had been developed in several countries and a foundation for it was laid down in England as the result of research carried out by Professor Jenkin and others, but the contribution of Junkers was outstanding, as subsequent developments have shown.

Increase in the power of engines, in conjunction with the decrease in their weight per horse-power, led to a marked reduction in the total amount of weight lifted for the power employed. Thus the weight of a single-seater reconnaissance machine, which in 1914 averaged 20 to 25 lb. per h.p. employed, was reduced by the end of 1918 to about 8lb. per h.p. Obviously this resulted in considerable increase in the rate of climbing and latterly some machines of that type could reach 10,000 ft. in about 5 min. and 20,000 ft. in less than half an hour. Wing loading was also much increased, this being made possible by the use of improved wing sections and greater structural strength. It will be recollected that the Wright brothers used a loading of 2 lb. per sq. ft.; by 1914 the average was about 4 lb. and by 1918 a loading of 8 lb. per sq. ft. was

commonly employed. The increases in speed which resulted have already been referred to. In 1918, 130 m.p.h. was quite usual, and some machines attained 140–155 m.p.h., which represented about double the speed of 1914.

Increase in the size was of course also a feature of the war-period development. Previously only a few aeroplanes had been constructed with more than one engine—the Short twin-engined biplane of 1911 was an early example—and their weights fully loaded were probably not more than about 2 tons. During 1916 the Handley-Page twin-engined biplane was produced in this country and it was followed by others, both here and abroad. which represented a considerable increase in size and hence in capacity to carry load. By 1918 aeroplanes weighing 10 tons when fully loaded had been constructed and in some cases as much as 4 tons of that weight consisted of crew, fuel, etc.—*i.e.* that part of the total weight which is termed the " useful load." This was perhaps the most significant development of all; the foundation was being laid for the application of the aeroplane for commercial use.

The entry in 1917 of the United States of America into the war gave considerable impetus to aircraft production in that country. It is stated that 3,288 aeroplanes of de Havilland and Handley-Page types were constructed during the war period and large numbers of aero engines were produced for home use and for export to the allies. As the American aircraft industry received its stimulus later than that in Europe, advance in design and construction was not so marked and was perhaps most evident in engine design; the " Liberty " engine, which resulted from the co-operation of automobile engineers, was an outstanding example and some 13,000 were produced.

At the conclusion of hostilities in 1918 the British air force was undoubtedly the most powerful organization of air power in the world, though in number of " first-line " aircraft it held second place. The supremacy was due to the effectiveness of the aircraft employed and to the personnel, which attained a very high standard. Demobilization and a consequent stagnation in aircraft production followed, pending the organization of civil air services. A large number of men and machines were released which provided the basis for the post-war development in which—as will be seen later—Great Britain was active. It cannot be denied that during the early development period this country lagged behind, but the ascendency gained in the latter part of the war was a turning point, and in aircraft production and in flight achievement the years which followed showed that the lead was to be maintained.

Some further reference to the use of aircraft for offensive purposes is desirable here. As already noted in Chapter VII, the first application of aircraft for bombing was that carried out by airship against Antwerp on August 25 1914, and the first raid over England took place on January 19, 1915. Bombing operations were also undertaken by the British Naval Air Service in 1914 and 1915 against Cuxhaven, Düsseldorf and Friedrichshafen. Zeppelin airships continued to be employed for attack on London and other centres, mainly by night, until the latter part of the war when, due to the vulnerability of the airship, large bombing aeroplanes were employed and raids were undertaken during the daytime. It has been calculated that the total weight of bombs dropped on this country during the war was 282 tons, of which 206 tons were dropped from airships; the amount dropped over London alone has been estimated at 50 tons. The total number of deaths resulting from all air raids on England and Scotland during the active period of

nearly four years is recorded as 1,413, and, taking everything into consideration, the loss of life and damage was not great. The moral effect of such raids on civil populations could not, however, be ignored, and it was that factor which largely determined subsequent military strategy.*

There was little doubt, in view of the technical developments of later years and the possibility of operations on a considerably larger scale, that the effects of attack from the air in future would be very much greater, and any conclusion based on the analogy of bombardment by artillery was accepted with caution. There was, of course, a corresponding development in the means for defence, *i.e.* in anti-aircraft gunnery, detection and in action by fighter aircraft, but the efficacy of such defence was undetermined. The later development of our warfare is described in Chapter XIV.

As in the case of the war on land, so in the war in the air, supremacy depended ultimately on numbers, though the balance was influenced periodically by better performances on one side or the other due to the introduction of a more powerful engine or to the reduction in weight by improvement in constructional detail. The competition which was brought about—not only in numbers of aircraft, but in performance—was stimulating to technical development, but it remained to be seen whether in the end the stimulation of the war period would have furthered the utility of flight or, by creating an abnormal background, have hindered its true development.

We come now—according to the arrangement of this book—to the close of what may be regarded as the historic era in the development of human flight. Any such demarcation is, of course, arbitrary, but the influences and conditions of the war period, which ended on November 11, 1918, are of peculiar significance in this subject and their termination with the advent of peace marked the beginning of a new epoch—that of the application of aircraft for the purposes of commerce by the organization of air transport services.

* The subject is dealt with in "The German Air Raids on Great Britain," by J. Morris, 1935.

PART III. THE MODERN PHASE

XII. THE INAUGURATION OF AIR TRANSPORT

(Third Great Period of Achievement)

1919–1929

AN ATTEMPT HAS BEEN MADE in the first and second parts of this book to describe the evolution of the idea of human flight and its subsequent realization in the invention of the airship and the aeroplane. It will be quite apparent that an advanced stage in the development of both these kinds of aircraft had been reached by the end of the first World War in 1918, but they had not been applied essentially for furthering human intercourse; or in any commercial way except for a short time just before the war. In fact the reverse was the case, since the activities of the last four years had been directed towards destructive ends.

The year 1919, however, marked the beginning of a new phase—that of the modern development under conditions of peace and directed to more profitable purposes. The decade which followed produced many remarkable flights, including the crossing of the Atlantic, but its most significant feature was the inauguration and development of regular air transport on a commercial basis—the achievement about which the early pioneers had dreamed. For this reason alone it may be regarded as constituting a third great period of achievement, but it was distinguished also by technical development on sounder lines than those hitherto followed. The period is in many respects comparable to that which followed the Second World War (1939–45) when an intensive development in civil air communications took place; but in the latter case the transition from military to commercial use was more rapid. It may be asked why the year 1929 is chosen as the termination of an outstanding period. The definition is perhaps arbitrary, but it is based on the fact that civil aviation, as distinct from military aviation, had completed the first decade of its existence and had shown that by the possession of greater speed—the feature most essential to modern transport—air travel was superior to the earlier means of travel by land and by water. Moreover, the years which followed were devoted to the growth of regular air services throughout the world rather than to any fundamental change of attitude, or alteration in the lines already laid down.

On conclusion of war, attention was directed to the possible utilization of the highly developed aircraft (both airships and aeroplanes) for commercial purposes, and as the bomber type of aeroplane was clearly more suitable for commercial purposes than the fighter type on account of its load-carrying capacity, some of those machines were adapted. The cost of production and upkeep during the war period had not received consideration on a commercial basis and in consequence the foundation for civil aviation and organized air transport had not been laid down. There was a marked retardation in the design, construction and production of aircraft in most countries during

the years which immediately followed, and this was due mainly to the impoverished state of the belligerent nations. The development of the aeroplane for civil uses advanced most rapidly in the United States of America and in Germany during the first years of peace. The latter country was prohibited under the Treaty of Versailles from making any expenditure on military aviation, and in consequence she directed her energies to the design of efficient transport machines—which were produced also in other countries to the design of German manufacturers—and to the advancement of aerodynamic knowledge by the experiments in gliding and soaring flight with motorless machines which have been referred to in Chapter IX.

The development of air transport services in Europe depended naturally upon some agreement between the various countries over which those services were to operate. As early as 1910 an attempt was made at a conference held in Paris to draw up an international agreement for the control of traffic by air, but the effort was abortive as insuperable differences of opinion arose. In 1917 the British Government set up a Civil Air Transport Committee to consider the same questions, and in 1919 the convention known as the International Air Convention was drawn up at the Peace Conference in Paris. This convention was the subject of a good deal of criticism from the standpoint of the restrictions which, it was alleged, it imposed on civil aviation in the interests of nationalism.

The development of air services required survey and preparation of routes. In May 1918 a trans-continental air mail service between Washington, Philadelphia and New York had been inaugurated and a system of ground organization was later perfected. This appears to have been the first successful attempt to employ the aeroplane commercially, for it proved the value of mail-carrying by air and also demonstrated the remarkable reliability of the modern machine. In England a civil aviation department of the Air Ministry was formed during February 1919 to deal with the survey and preparation of air routes for the British Empire, to organize wireless telegraphy and meteorological services, and to undertake the licensing of civilian pilots, machines and aerodromes. Civil flying in the British Isles was permitted officially as from May 1, 1919, and passenger-carrying and exhibition flights—which had not been possible during the war period—were resumed. On August 26, 1919—a date which will be historic in this country—a daily air service between London and Paris was inaugurated by a company known as Air Transport and Travel, Ltd. Two passengers were carried in cabin machines and the single fare is said to have been twenty guineas. During September the Handley-Page Company provided an alternative day service to Paris and Brussels with machines carrying ten passengers. French companies were also operating and tentative services were inaugurated in Europe, notably from Berlin to Weimar, Hamburg and Breslau. On November 10, 1919, air mails were first despatched regularly from England.

In spite of the remarkable pioneer flights by British airmen which were undertaken during 1919 and the following years—flights which contributed much to national prestige and will be historic—progress in design, and particularly in production, was by contrast slow in this country during the decade now under review. The demand for air transport services in the

British Isles, in view of the existing communications and the comparatively short distances, was not regarded as great, and this consideration has certainly influenced development. Those who had hoped that the improvement of aircraft would result in a boom in civil aviation after the declaration of peace were disappointed, and it was necessary to wait several years for a revival of that activity in design and production which was characteristic of British enterprise during the war. It is not proposed to attempt to analyse the causes of this unfortunate retardation; they were in part psychological and in part economic and the result serves to emphasize the national tendency in regard to aviation, which appears to consist in profiting as much as possible from the experience of others, and, in accordance with some unknown cycle, rising at intervals to surpass all foreign effort.

There was, however, a remarkable advance in the efficiency of aero engines—an advance which was very apparent during the latter part of the war. In particular the radial type was developed in this country and the 400 h.p. "Jupiter" engine, the manufacture of which was taken over by the Bristol Aeroplane Company, proved by 1922 so efficient, light and reliable that its performance was strictly comparable with that of the established water-cooled type of engine. The Armstrong-Siddeley "Jaguar" was another example of this type which had proved very efficient and was widely employed at home and abroad. Development of the V-type water-cooled engine continued in the production of the famous Napier "Lion" and Rolls-Royce engines; power units exceeding 400 h.p. were well established.

During the spring and summer of 1919 several attempts were made to fly the Atlantic in an aeroplane in competition for a prize offered by the *Daily Mail* Among others, H. G. Hawker and Commander Mackenzie Grieve attempted a flight, which was undertaken in a Sopwith biplane, but they were forced to descend in the sea when about 750 miles from the British Isles owing to engine failure. On June 14 and 15, however, the first non-stop transatlantic flight was accomplished in an aeroplane by the late Captain Sir John Alcock, with Sir Arthur Whitten Brown as navigator; the second flight was that of H.M.A. R.34 on July 2–6, 1919, already referred to in Chapter VII. The machine used (*see* Plate XXV) was an adapted Vickers-Vimy bombing aeroplane fitted with two Rolls-Royce "Eagle VIII" engines and the flight occupied 15 hr. 57 min. at an average speed of 118 m.p.h. over a distance approximately of 1,890 miles, the start being made from St. John's, Newfoundland, and the landing in Ireland at Clifden, Co. Galway. It represents a great event in the history of aeronautics, not only because it was the first non-stop flight across the Atlantic—which was an achievement as significant as Blériot's crossing of the Channel ten years before—but because it provided evidence of the reliability of the modern aero-engine and demonstrated that a large load-carrying aeroplane could be successfully controlled and navigated for a long period under very trying weather conditions. The airmen benefited from a following wind of about 20 m.p.h., but little was known at that time of the conditions of the North Atlantic and the flight indicated great skill both in piloting and navigation. It was an achievement which has not perhaps received all the notice it deserves; there still seems to be an impression in some quarters that the first non-stop flight was that accomplished by Colonel Charles Lindbergh from New York to Paris in 1927. Remarkable as that achievement was from every point of view, there should be no confusion as to the facts

regarding the first direct crossing of the Atlantic by air. The Vickers-Vimy aeroplane used has been preserved in the Science Museum since 1920.

Shortly before Alcock and Whitten Brown's flight, three Curtiss flying boats of the United States Navy began to fly across the Atlantic in stages from New York to Portugal. After many vicissitudes Lieutenant Commander A. C. Read on the NC–4 reached Lisbon on May 27, 1919, *via* Newfoundland (which he left on May 16) and the Azores. It was thus actually the first crossing of the Atlantic on a heavier-than-air machine.

In pursuance of the British Government's policy of exploring the possibilities of air services through the Empire, some remarkable flights were undertaken by the Royal Air Force during 1919 and the succeeding years. The first flight to Egypt from this country, or from the Continent, was made during July 1919 in a Handley-Page bomber, type O/400, piloted by Squadron Leader A. C. S. MacLaren and carrying several passengers. Nearly 3,000 miles were flown on the route from England *via* Paris and Rome to Cairo and finally to Palestine. The aircraft could carry a load of about 2,700 lb. with a range of some 500 miles at about 95 m.p.h. and it was fitted with two Rolls-Royce " Eagle " engines. It was a useful demonstration of what could be done with the aircraft available at that time. During November the same machine was flown on to India by Captain Ross Smith and it arrived at Delhi on December 12, 1919. During the same month a four-engined Handley-Page night bomber, type V/1500, left England on the first direct flight to India, piloted by Squadron Leader MacLaren and Lieutenant R. Halley. It carried a total load of 10,000 lb. with a range of about 1,000 miles at a speed of 95 to 103 m.p.h.

These two flights demonstrated the value of the aeroplane as a long-distance transport vehicle and its importance to the British Empire both in defence and in trade. They also paved the way for the regular air services which followed some years later. Similarly, the first flight to Australia by Captain Ross Smith and Lieutenant Keith Smith on a Vickers-Vimy biplane served to explore the possibilities of the through route. They left Hounslow on November 12 and reached Port Darwin on December 10, 1919—a distance of 11,130 miles which was covered in 124 hours actual flying time. The flight was continued across Australia and the total distance flown was about 15,000 miles. During 1920 a second flight to Australia, on a two-seater D.H.9 aeroplane, and the first flight to Cape Town, on a Vickers-Vimy machine, were undertaken.

Development on a commercial basis, however, proceeded slowly in this country. Reduction in the prime cost and in the costs of maintenance was essential if organized air transport was to be profitable. Safety and reliability were of paramount importance, and these depended in no small degree on efficient ground organization. The development in all countries during the next few years was directed to obtaining a reduction in the costs of production and upkeep with increased reliability; this involved the designing of new types, in addition to the improvement of the standard types of the war period for service purposes. The new commercial aircraft were designed to carry a definite load which could be distributed to the best advantage within the body of the machine and not, as previously, in part outside it—as in the case of machine guns, etc., the location of which was determined by their

functions. In consequence there was freedom to arrange loads to suit the structure, which tended to simplify and reduce structural weight and therefore to increase the useful load. The costs of construction and maintenance were thus also reduced. The high speed attained by the machines of the war period, at considerable cost in fuel consumption and maintenance, was no longer sought, but rather an economical average cruising speed which could be easily maintained over long distances. It was found that by designing for maximum efficiency at the desired average cruising speed—which meant in practice fuel consumption per ton-mile—an appreciable increase in the total weight carried per horse-power could be effected. Improved design and increased engine efficiency enabled a margin of power to be maintained, as engines were not constantly run at full power, and by reducing wear and tear greater reliability was obtained with longer periods between overhaul. There was at this time a tendency to increase the wing-loading of commercial aircraft as it was found to be necessary if speed was to be increased and efficiency maintained. But this, of course, necessitated also a higher landing speed with its attendant disadvantages and danger in forced landings.

High cruising speeds were not then regarded as of such importance as they are to-day, when transport efficiency has been defined as " pay load multiplied by speed and divided by engine power "; nevertheless the performances were good, and high landing speeds had to be accepted as inevitable to high commercial efficiency. Obviously the ideal was a combination of heavily loaded wing with the capacity to land at low speeds, and it was the goal of designers then as it is to-day. Several devices, such as the Fairey and Dayton-Wright variable camber gears were introduced in order to solve the problem; they were designed to modify, by mechanical means, the section of a normal wing when taking off, climbing and landing, to render it capable of exerting a higher maximum lift on those occasions.

The slotted wing, which was introduced by F. Handley-Page at this time, consisted of a normal type of wing pierced near the leading edge by a slot, or slots, of peculiar shape, sloping backwards from the under-surface to the upper. It was found that such a wing with a slot, or slots, extending across the whole wing, and dividing it up into a series of narrow sections, gave a very much higher lift than the same wing without slots. It was stated that an extra loading of as much as 60 per cent. could be carried by such a wing with one slot without increasing the landing speed, and by using several slots as much as 100 per cent. increase could be obtained. The slots could be opened or closed by mechanical means so that a normal low resistance wing was available for normal flight and the high lift quality available for landing at slow speed, etc. The slot was applied also to aileron control in such a way that when an aileron was pulled down it opened another slot and still further increased the maximum lift of that wing, thereby assuring adequate lateral control at a slower speed. In addition to making low landing speed possible with all-round efficiency, the slotted wing can materially assist in the prevention of that dangerous state of instability resulting from loss of flying speed known as " stalling," which, when followed by spinning, has been the cause of many fatal accidents. The Handley-Page slotted wing system has been widely applied and used, in conjunction with flaps, to give extra lift when flying at large angles of incidence.

An alternative method of reducing the difficulties of landing with highly

loaded wings—which, as already explained, were necessary for efficiency—was to employ thick-section wings of the type known as "high-lift," having a high maximum lift coefficient. Unfortunately such wings had also a high resistance to forward motion and did not favour the accomplishment of fast cruising speeds save at the expenditure of much power, so their adoption was by no means universal. There was, however, considerable development from the year 1920 onwards, and to-day we owe much to that activity. Reference has already been made to the introduction by Hugo Junkers in 1916 of his cantilever system of deep or thick-section wing, and to his famous patent of 1910 for an "all-wing aeroplane." It has been stated that the idea originated in France, but the author has been unable to trace any evidence of use prior to the patent of 1910. However that may be, it is clear that the production in 1918 by the firm of Junkers of a monoplane with a "high-lift" wing section, and constructed entirely of metal, marks a definite stage. The machine was the forerunner of a series of very successful monoplanes—obviously the "high lift" wing cannot be made the best use of in multi-plane construction, which involves external bracing.

The new line of development consisted in accepting the "high lift" wing in spite of its inherent disadvantage in regard to resistance, and endeavouring to compensate for this by taking full advantage of its form, which enables it to be constructed without any external supporting structure, such as wing struts, wiring, etc., and thus to eliminate the usual resistances resulting from an externally braced wing. In 1920 the Dutch designer Fokker also announced the construction of a machine without any external bracing to the wings, which were of deep section enabling the whole of the supporting structure to be contained within the wing itself. Such a form of construction went far to compensate for the extra resistance of the "high lift" wing. A number of monoplanes were evolved on this principle which compared favourably with machines of the conventional type with regard to performance and ratio of useful load to the power supplied. The general simplicity and cleanness of design resulting from the absence of rigging tended to reduce the costs of maintenance in overhauling and inspection. The thick wing naturally lends itself to metal construction, and in the case of the Junkers aircraft the wing covering was also of metal. Later, the type was developed in the United States of America and, finally, in this country.

During 1922 and 1923 the use of metal in aeroplane construction became an accepted line of development in several countries, especially in regard to service machines, where the advantages of metal, as opposed to timber, in storage, etc., were of importance and aided the maintenance of aircraft in good condition for immediate use. Metal construction was also found less costly than timber construction to maintain. The use of steel, in the form of sections built up from strip metal, was adopted in England, whereas in other countries the use of light alloys, such as duralumin, found favour. It was generally accepted that the use of steel involved greater difficulties in aircraft construction than the use of light alloys, but in view of the comparatively unknown degree of reliability of the latter under working conditions the use of steel was fully justified. Aeroplane structures made of steel were proved to be both lighter and stronger than those constructed of timber. The cost was higher, but the fact that metal is less liable to deteriorate when stored. and also in use, would appear full compensation.

Little advance was made in the construction of purely commercial aircraft during the years 1921, 1922 and 1923, either in Europe or in America, but racing machines were developed in the latter country and a speed of 266 m.p.h. was attained during 1923. In England the light, low-powered aeroplane was developed, and a competition held at Lympne in October 1923 demonstrated the greatly improved performances of this type of aircraft. The "Wren" cantilever monoplane, designed by W. O. Manning, which was actually a high-performance glider fitted with an "A.B.C." engine of nominally 3 h.p., achieved the very remarkable feat of flying 87·5 miles on one gallon of petrol. The light aeroplanes demonstrated were generally successful, and they suggested a new line of development with the object of evolving a type of aeroplane which would appeal to the private owner and popularize flying. It was found, however, that the ultra-light machine was not, for various reasons, the best type for that purpose, and a tendency was soon apparent to compromise by developing a slightly heavier and therefore more costly construction.

During 1924 several notable flights were performed over territories unprovided with facilities for rapid transport, thereby demonstrating the utility of the aeroplane under such conditions. Among these flights should be mentioned that of Lieutenant Pelletier Doisy and Sergeant Besin from Paris to Tokyo (April 24–June 9) on a Breguet biplane, the distance covered being 11,500 miles in 120 flying hours; the round-the-world flight undertaken by American army aviators during the period April 7—September 28 on four Douglas "World Cruisers," the total distance covered being 27,534 miles in 351 hrs. 11 min. flying time; and the flight of Lieutenant R. L. Maughan, of the U.S.A. Air Service, from New York to San Francisco on July 23 on a Curtiss biplane, the distance covered being 2,670 miles in 18 hrs. 26 min. flying time. In addition, two important flights were made round Australia by British airmen, when a distance of 8,568 miles was covered in 90 flying hours and 7,658 miles in 81·45 flying hours. A flight from London to India (Rangoon) and back (November 20, 1924 to March 17, 1925) was made by Air Vice-Marshal Sir Sefton Brancker, piloted by Sir Alan Cobham on a D.H.50 biplane, when a total distance of 17,000 miles was covered in 220 hours flying time. Work in forest patrol, timber and topographical survey was undertaken by aircraft in Canada with considerable success. At the end of 1924 the world's records for aeroplane performance were: speed, 277·805 m.p.h.; duration, 37hr. 59 min. 10 sec.; altitude, 40,783 ft.; greatest distance without landing, 2,511 miles.

The year 1924 is specially notable in the development of organized air transport in the British Empire, because the subsidized company Imperial Airways, Ltd., was formed then to amalgamate the four existing air transport companies into a national body with a view to concentrating on air services in Europe and beyond. Its foundation was an event of importance in the development of air travel, and in the first six years of its existence it established a record of efficiency, reliability and safety which was unsurpassed by any similar organization. The record was well maintained, and considerable progress was later made in the extension of the Company's air routes throughout the Empire. This subject will be referred to later. In the United States of America a trans-continental air mail service was restarted in 1924 and subsequent legislation brought air navigation under government control.

In 1924 the British Government framed a new airship policy. It was decided to construct two airships, to be known as the R.100 and the R.101, the former to be built by the Airship Guarantee Company, and the latter at the Royal Airship Works, Cardington. The two ships were to be larger than any hitherto constructed, and were to represent a considerable advance in design by increase in size, carrying capacity and speed, the aim being to explore thoroughly the possibilities of lighter-than-air transport on a commercial basis. They were not completed until 1929, but it is convenient to record here the conclusion of the experiments, because they terminated—for the time being anyhow—airship development in this country. During October 1930 preparations were made for a maiden voyage to India, with the intention of exploring the possibilities of a regular commercial air service on that route—a voyage which ended in a tragic disaster, as grievous as any in the history of airship development. The R.101 set out from Cardington, Bedfordshire, on October 5, and the airship carried, in addition to the crew, a distinguished company as passengers, including the Secretary of State for Air. Lord Thomson, all of whom perished. When near Beauvais, France, the airship was forced down, due to leakage of gas, crashed, and took fire, the only survivors being six members of the crew. As a result of the disaster, and the findings of the official court of inquiry, the government programme for airship development was considerably curtailed, though it was decided to retain the R.100 in commission for further experimental work.

During 1925 and 1926 useful work was done by Sir Alan Cobham and others in making flights to and from various parts of the British Empire with a view to emphasizing the importance and possibility of imperial air services. Continental air services were being developed at this period to give increased scope and regularity.

The years 1926 and 1927 saw the end of that period of depression in the aircraft industry which had followed the war and a new era in aeronautical history may be said to have begun. In England there was an increased tendency to use steel in aircraft construction, metal structure having been developed to such an extent that machines were supplied in quantity to the Royal Air Force. Notable development also took place in flying-boat and light aeroplane construction. Light aeroplane clubs were formed during this period, popular flying being rendered possible by the advent of the highly successful de Havilland " Moth " light aeroplane and other machines.

In contrast to development on normal lines, there appeared at this time (1926) a heavier-than-air machine which was entirely novel in conception. The Autogiro, designed by Senor Don Juan de la Cierva (1895–1936) is a machine which embodies some novel features in that it is provided with rotating vanes mounted on a nearly vertical mast which is situated above the centre of gravity of the machine. These rotating vanes, or wings, having been given an initial rotation while on the ground, are caused to continue to rotate by virtue of the forward motion of the machine—which is provided with a conventional type of body containing an engine with tractor airscrew—and thereby furnish the necessary lift. The principal advantage accruing from this type of heavier-than-air machine is that it permits of an almost vertical descent being made with safety, by virtue of the supporting surfaces being in rotation. The aerodynamics of this form of rotating-wing machine are of a complex nature, and it is not feasible to discuss the matter here. The

Autogiro, as designed by de la Cierva, has been developed since its inception with remarkable success, and it has now been modified so that an initial vertical ascent is possible in addition to the almost vertical descent. Speeds exceeding 100 m.p.h. are also attained without sacrifice of those special qualities. The machine may well provide the ultimate solution of the problem of taking off and landing an aircraft in a very restricted space when such operation is essential.

During 1927 several remarkable non-stop flights were made across the Atlantic, the most enterprising being that of Colonel Charles Lindbergh, who on May 20–21 flew alone from New York to Paris, a distance of 3,600 miles, in 33 hr. 30 min., on a Ryan monoplane fitted with a Wright " Whirlwind " engine of 220 h.p. This was followed by a non-stop flight from New York to Eisleben in Germany on June 4–6, achieved by Messrs. Chamberlain and Levine on a Bellanca monoplane, also fitted with a Wright " Whirlwind " engine, the distance being 3,909 miles, covered in 43 hours. While Lindbergh was flying the Atlantic, Flight-Lieutenants C. R. Carr and L. E. M. Gillman, R.A.F., flew non-stop from England to the Persian Gulf on a Hawker " Horsley " biplane fitted with a Rolls-Royce " Condor " engine, a distance of 3,419 miles, which was covered in 47 hr. 23 min.

The boat type of seaplane underwent rapid development at this time, and large seaworthy craft such as the " Calcutta " and "Singapore," designed by Short Brothers, and the Supermarine Aviation Company's " Southampton " type were evolved. High-speed racing seaplanes were being developed in several countries to compete for the Schneider Trophy, which was won, in 1926, by the Italian Macchi, M.39, float-seaplane, which machine subsequently established a world's speed record of 258·5 m.p.h. In 1927 the Schneider trophy was won for Great Britain by the Supermarine-Napier S.5 racing seaplane at an average speed of approximately 281 m.p.h. The world's speed record for this type of aircraft was raised by Major Mario de Bernardi in 1928, when he achieved a speed of 318·464 m.p.h. on the Italian seaplane Macchi 52 bis.

Many long-distance flights were made in different parts of the world during 1928, and the scope, range and reliability of the aircraft in use indicated that a high degree of general efficiency had been obtained. The first direct transatlantic flight from East to West was accomplished on April 12–13, 1928 in the Junkers monoplane "Bremen," piloted by Captain Herman Koehl and Colonel J. H. Fitzmaurice and carrying Baron Guenther von Huenefeld as passenger. The records of landplane performance at the close of 1928, which serve as a fair criterion of development, were: greatest distance without landing, 5,062 miles; duration, 65 hr. 25 min.; speed, 277·805 m.p.h.; altitude, 41,794 ft. The most important feature, however, was the rapid growth of civil aviation all over the world, indicating that the aeroplane had at last become an instrument of real utility.

In 1927 the Zeppelin Company (Luftschiffbau-Zeppelin) had resumed work at the factory at Friedrichshafen by the production of standard parts for the construction of a new airship, and a vessel of some 3,710,000 cu. ft. capacity, designated L.Z.127, was constructed. The airship, which is best known by the name of " Graf Zeppelin," was completed in 1928, and launched on September 18. Many notable flights were accomplished and, later, a regular transatlantic service was operated. On October 11, 1928, the airship

left Friedrichshafen for Lakehurst, N.J., U.S.A., with a crew of 40 and 20 passengers, under the command of Dr. Eckener. In spite of unfavourable weather the journey of approximately 5,000 miles was completed in 4 days and 15·5 hours. During the summer of 1929 the " Graf Zeppelin " made a remarkable flight round the world. This flight started from Lakehurst on August 8, when, passing *via* the Azores, the Scilly Islands and Paris, the airship reached Friedrichshafen in the then record time of 55·5 hours. From thence the vessel flew direct to Tokyo, a distance of nearly 7,000 miles in 101·75 hours. After a short stay at Tokyo, the journey to Los Angeles across the Pacific, a distance of 5,400 miles was covered in about 79 hours, and the final stage to Lakehurst across the North American continent, some 3,000 miles, was undertaken in under 52 hours. The total distance traversed on this remarkable journey was estimated at about 21,500 miles, and the whole time occupied was just three weeks, of which only about twelve and a half days were actually spent in the air, the resulting average flying speed being about 78 m.p.h. The performances of the " Graf Zeppelin " served as an indication of the reliability and safety in operation which could be obtained by a rigid airship, and they provided evidence of the advanced stage which had been reached in the development of that type of aircraft. The use of airships in commercial air transport will be considered in the next chapter.

It has been said that by the end of 1929 over 100 persons had crossed the North Atlantic by air, but this was not of great significence when the circumstances under which most of the flights were made are taken into consideration. The operation of regular transatlantic services by aeroplane obviously depended on further research and development. Most of the crossings accomplished were of a very hazardous nature, and from the practical standpoint, yielded little knowledge that was not already available. The development of aircraft suitable for service under those conditions was what really mattered, and, in addition to the progress made with the " Graf Zeppelin," there was indication that a type was being evolved which might ultimately serve that purpose. In 1929 a remarkable passenger-carrying flying boat, known as the Dornier Do. X, was produced in Germany. It was, at that time, the most powerful aeroplane and possessed the greatest lifting capacity of any constructed. Twelve Siemens " Jupiter " engines each of 525 h.p. were installed and the machine was capable of carrying some 100 persons; in fact on one occasion it carried 169 people. A significant feature was the centralization of the control of all engines, the responsibility for them and the immediate control being in the hands of the chief engineer answerable to the commander of the aircraft. Though the Do. X was, perhaps, conceived on an over-generous scale, and was not put into regular operation on any service comparable to that which has just been considered, it deserves to be regarded as a pointer to the form and construction which was being developed (*see* Plate XXVI).

In concluding this brief survey of development during the first decade of organized air transport, it is of interest to quote some figures which are a fair criterion of commercial progress. Taking 1920 as the first complete year of operation we find that, on regular air services throughout the world, the route mileage was 9,700 and the total miles flown 2,969,000.* In 1929 these

* The figures for 1919 were : route mileage, 3,200 ; miles flown, 1,022,000. In all cases the route mileage is approximate and the miles flown partly estimated.

figures were 125,800 and 53,379,000. respectively. During 1920, 3,622 flights were made between the United Kingdom and abroad and 6,383 passengers (as distinct from operating personnel) were carried; these figures were increased in 1929 to 9,236 flights and 48,253 passengers, indicating that, in addition to better patronage, the accommodation of the aircraft had much increased. The value of the goods imported into and exported from Great Britain by air was nearly trebled during the nine years. Air transport was well established, but it was not, except in rare cases, self-supporting in a commercial sense. It relied on financial assistance from governments in some form or other. This might be by direct subsidy or by guaranteed payments for mails carried, and the equipment and maintenance of air routes by the state.

XIII. EVOLUTION OF AIR TRANSPORT

THE DEVELOPMENT OF AIR TRANSPORT is a large subject and it is obviously far beyond the scope of this book to deal with every aspect of it or to attempt to describe all that has been achieved. There are, however, certain aspects which demand consideration here if the extent and purpose of flight is to be understood. Clearly air transport is still in its infancy; if we reflect that established mechanical transport on land by means of the railway and on water by means of the steamship is little more than a century old, it is apparent that transport by air is relatively young, for it has little more than two decades of organized practice behind it. Yet it has advanced far beyond the stage reached in travel by rail or steamship during the corresponding period of their use. Judged by the standards of safety and comfort existing in other methods of transport, the commercial aircraft is not at a serious disadvantage—indeed, some would maintain that it is an advantageous position—and it possesses the very important advantage of flexibility of route which is not shared by land transport. In view of the rapid progress which has been, and still is being made in the technology of mechanical flight and in its application, it is obvious that finality has not yet been reached; in fact the indications are that development will continue to proceed rapidly unless some social or economic disturbance again intervenes.

In this connection it must, however, be realized that aeronautics has probably been influenced more by abnormal circumstances than any other branch of technology; it has advanced most rapidly during times of relative economic freedom when the normal standards of what does and does not pay no longer applied. Thus the social upheaval represented by two world wars played an important part in the development by providing a stimulus at two periods—the general advances achieved during the Second World War are no less profound than those of 1914–1918. What is now required is a long period of peace and ordered progress so that the flying machine may be applied constructively to international transport and its vast potentialities as an instrument of human intercourse realized.

The basic consideration in regard to air transport is, of course, what it has to offer in comparison with the older methods of travel. Speed and flexibility of route, with a great saving in time where land and water have to be crossed are the outstanding advantages. Against these is the cost which—disregarding for a moment the factor of time saved—is generally greater. If time is valuable to the traveller the extra cost of transport by air will be justified, and we find that the air services of the world cater at present mainly for such people, though there are some who travel by air simply because they consider it more comfortable and prefer it. Naturally air transport competes to some extent with the other methods and in the future, if the costs are reduced, the competition will be more apparent. Quite apart, however, from that consideration, aircraft have their own sphere of operation, *i.e.* where time saved is of great importance and where there are no communications or only very poor ones. Obviously the qualities of speed and flexibility of route have

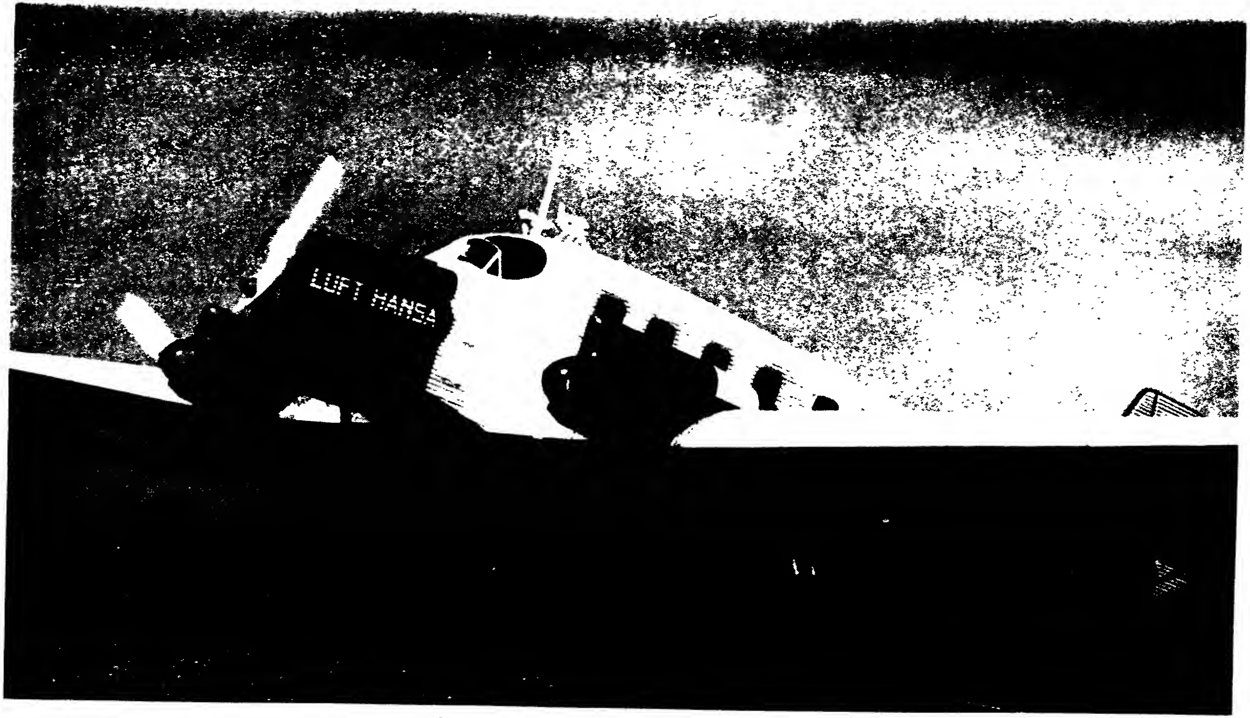
favoured the growth of air transport, but the existence of an extensive network of land communications in most European countries, in the United States of America and in the Union of Soviet and Socialist Republics has rendered any alternative means of travel uncalled for unless those special·advantages were fully realized.

Great scope for the development of air transport lies in continents such as Australia, Africa and South America, where the distances are enormous and the communications few, and in a lesser degree in the U.S.A. and the U.S.S.R. That may be described as trans-continental or internal air transport, but there is further scope in providing means for rapid communication between different countries and continents separated by a varying expanse of sea—in effect, inter-continental air transport.

It is with regard to the latter that we are most concerned in this country. The aeroplane can by providing rapid communication between the countries in the British Empire and Commonwealth render a service which is vital in progress. This probably represents to us the most profitable of all the uses to which the aeroplane may be put, because the distances are very great and the existing communications, in regard to speed, inadequate. The linking of these several countries by air represents a profound achievement because it is directed towards the solution of a major problem—that of unrestricted and rapid intercourse between the peoples of the world. When we reflect that the air services of the British Empire in 1939 operated not within the frontiers of one country or the limits of one continent but traversed four continents and some thirty countries, the achievement obtains an even greater significance. The operation of such services presented many difficulties, arising from the acute nationalism which developed in many countries during the inter-war period; national prejudices resulting from the play of international politics had to be overcome and agreement with the various foreign governments secured. The condition of the world and particularly Europe at the end of the Second World War was not conducive to the successful development of international air transport, and until it is possible to concede the principle of freedom of the air—on the analogy of the earlier freedom of the seas—the best use will not be made of the power of flight.

There is a third category of air transport which rests on a different footing; it is internal air communication in small countries, such as England, and is thus primarily national. It is appropriate to consider this aspect of air transport first. The internal air services of the British Isles are of comparatively recent origin. There were no internal air lines in 1930 and it was uncertain whether there ever would be, because the distances are relatively short and the communications good, while the weather conditions for flying are not of the best. It was mainly the distribution of population and the fact that there were still gaps to be bridged, particularly over water, which created the need. There is a loss of time in surface communications where water has to be crossed; the change from land to water and vice versa often upset schedules despite most careful organization, and the benefit of travelling by air without changing is very evident. Thus the bridging of water gaps gave scope to the aeroplane and it was the foundation of air lines in the British Isles; the services to the Isle of Man and the Isle of Wight were examples of such operation. In addition, there was the need for communications with outlying places, which were badly served, such as the Orkney and Shetland

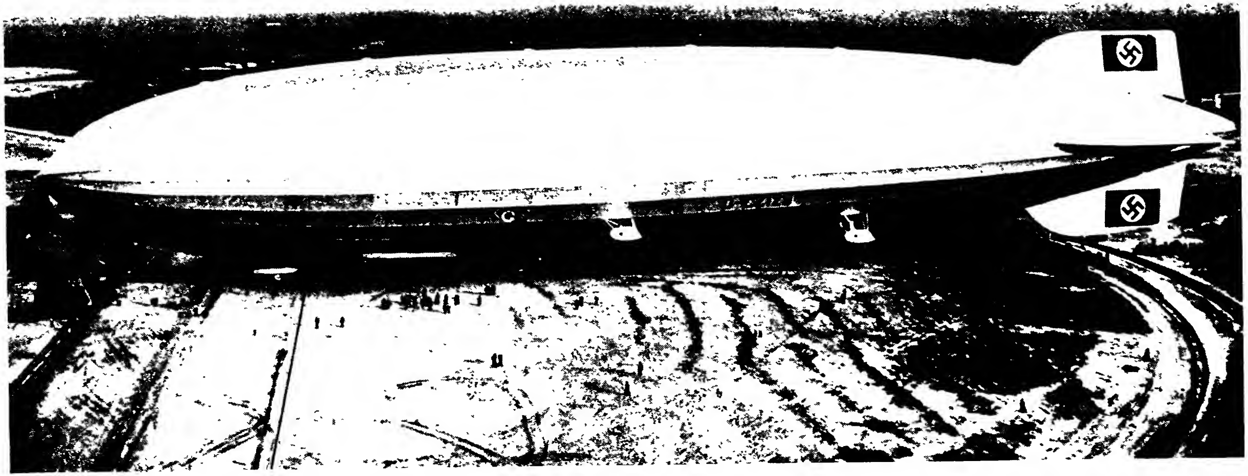
PLATE XXVIII



Junkers Commercial Aircraft, G.24. 1924

An eleven-seater air liner with three Junkers L 5 engines of 300 h.p. each. Employed by Luft Hansa on services in Central Europe. See *Page* [illegible]

PLATE XXIX



The Zeppelin "Hindenburg" at the Mooring Mast, Lakehurst, U.S.A., 1936

Represented the highest standard then attained in the development of the rigid airship, and was employed on the transatlantic services inaugurated by the "Graf Zeppelin."
Destroyed by fire at Lakehurst, May 6, 1937. *See Page* 157

Pan-American Airways Martin Clipper Flying Boat, 1936

Employed on the trans-Pacific air service from San Francisco to the Philippine Islands, carrying passengers and mails. Maximum speed 180 m.p.h., with fuel for 3,200 miles (*See Pages* 158, 161)

PLATE XXXI

Imperial Airways Empire Flying Boat "Canopus," 1936

Designed specially to meet the requirements of the British Empire air routes and for transatlantic services, this flying boat had a maximum speed of 200 miles an hour. It carried 24 passengers with a crew of three and represented a most important advance in air transport equipment. Constructed by Messrs. Short Bros. Ltd. (*See Pages* 157, 161)

Isles. By 1933 sixteen air lines were in existence and by the summer of 1934 twenty-four were actually in operation. In 1933 one company alone (Hillman's Airways, who also operated between London and Paris) carried more than 9,000 passengers. During the following year the same company carried the first flat-rate, internal air mails under government contract—almost exactly twenty-three years after the first attempt to establish a short air mail service in England was made under official support. In 1935 three companies were amalgamated and formed British Airways, Ltd. There were then twenty-two air transport companies operating in and from the United Kingdom and the number of services was nearly double that of the previous year.* The regular operation of such services during bad weather—especially when fog reduces visibility—must depend largely upon the use of instruments and on good ground organization. In both these essentials considerable progress had been made and greater regularity had resulted.

Rapid communications between aerodromes and the centres of population which they serve is a problem which has to be faced if full benefit from the speed of the aeroplane is to be derived. The problem is particularly acute in the case of large cities where, for various reasons, it is not possible to place the aerodrome near the centre and communication by road is necessarily slow. A solution was found in one case by placing an airport on a main railway line with frequent train service to its own station. The Gatwick "all-weather" airport was located twenty-eight miles from London on the Southern Railway, and it was thus beyond the fog-belt which sometimes surrounds the metropolis. It is an illustration of what may be done to make the best use of air travel, and it is probable that in future airports will be linked by direct rail communication with the centres they serve.

The operation of trans-continental and inter-continental air services differs from that of short internal services in so far as the distance, and therefore the scope, is very much greater. In the case of a country like America there is vast scope due to the enormous distances; moreover there are, on the whole, better—or at least more constant—weather conditions and the country is probably safer for flying than Europe. The area of the U.S.A. is about four-fifths of Europe and it is all subject ultimately to one central government and in consequence all flying is under one administration. There are no frontiers and but one language and one currency. Much the same conditions are to be found in the U.S.S.R. and the scope for further development in both these countries should be great. In Europe, on the other hand, there was no centralized administration, for the continent was divided by many governments each with its national interests, and this division hindered the free development of air transport. Differences in language, customs and currency also mitigated against perfect organization. There is, however, the prospect that, following the Second World War, the organization of air transport on an international or at least co-ordinated basis may be possible, and it would appear that, in Europe at least, full benefit will not be derived from the use of the aeroplane unless such agreement is reached.

The trans-continental and inter-continental air services of the British Empire—Imperial Airways and other routes—operated, as already remarked,

* The Air Ministry "Reports on the Progress of Civil Aviation" gave information of civil flying in the United Kingdom and the Dominions, etc., with maps. The reader is referred to them for complete data.

over four continents and some thirty countries. The principal routes in 1939 were: England–India—Australia and England—South Africa. The former, operated by Imperial Airways, Ltd., to Karachi (4,868 miles), and from thence to Singapore (8,381 miles) in conjunction with Indian Trans-Continental Airways, Ltd., was continued to Brisbane (12,742 miles) by Qantas Empire Airways, Ltd., and throughout Australia by other companies. In 1937, the journey by air to Brisbane occupied about twelve days and some thirty-two days by other transport. The England-South Africa route was operated by Imperial Airways, Ltd., direct to Cape Town (7,885 miles), which was reached in about nine days, the journey by other transport being seventeen days. Places off the main route were served by other companies. The air routes of the British Empire were an imposing achievement when we consider the many difficulties which had to be overcome at that time.

In 1935, the various companies which had been operating to the Continent were amalgamated to form British Airways which received a subsidy as a second chosen instrument to serve on some routes in Europe. As the result of the report, in 1938, of a Committee set up by H.M. Government (the Cadman Committee), the British Overseas Airways Corporation was formed to take over the two earlier companies, but it did not come into being officially until April, 1940.

A few words here on the use of the aeroplane in civil aviation may be appropriate. There is no analogy in usage between the aeroplane and the motor car, or any other land vehicle, because the former involves navigation and the latter does not. The aeroplane is analogous to the ship and the pilot must be skilled not only in handling the machine, but in the use of compass, maps and other aids to navigation if he is to fly it across country. He has to take account of the wind, its strength and its direction. A head wind will affect not only his speed but also his fuel consumption and in consequence his range. These are factors which require specialized knowledge and training, and they are not factors which—for instance—concern the driving of a motor car. If the aeroplane is to be used regularly as a means of transport the pilot must have that knowledge and the ability to fly in varying weather conditions. It is doubtful whether the majority of persons who might contemplate piloting an aeroplane will have either the time or inclination to learn navigation or to acquire the experience which is necessary for safety. Clearly those who fly privately for their own business or enjoyment should be properly qualified, both in piloting and navigation, because if they are not they will be a danger to themselves and to others who fly, and possibly to those on the ground. Collision in the air is almost invariably fatal to both parties, and in consequence the strictest control is necessary in the vicinity of aerodromes, and, should aircraft increase considerably in numbers, control will be essential in every area where there is traffic. For these and other reasons it is obvious that there will be a limit to the amount of private flying which can be permitted. Congestion in the air would be much more dangerous and undesirable than it is on roads. There is at present no indication of even an approach to such conditions, but it is well to reflect that it might possibly come to pass and to plan accordingly. It is probable that the next generation will take to flying more readily, and, as aircraft increase in numbers, so more control and organization will be required; the only danger will be that the increase may come too soon and the ground organization be insufficiently developed. It

is probable that the future will show a great increase in professional flying, but without a proportionate increase in private flying. That should be all to the good, because the operation of air transport—indeed of any transport—is better and more efficiently undertaken by professionals than by amateurs; the piloting of aircraft should be vocational. We look to the future not for a marked increase in the number of those who will pilot themselves for pleasure or sport, but for a considerable growth in the number of those who will, as passengers, use air transport. Thereby will be derived the greatest benefit.

The matter of safety is necessarily in the forefront of development; it is the principal concern of all connected with the organization and operation of air transport. The highest standard is reached in air transport organized on a commercial basis. During 1935 error of judgment or faulty airmanship was the sole cause of accident to aircraft of all sorts in the United Kingdom in about 58 per cent. of the total cases.* It is thus apparent—from that particular instance—that the factor of human failure plays an important part. Mechanical failure (including engines) in passenger aircraft is relatively rare and becomes increasingly so. Air liners are now multi-engined, and it is the accepted practice to employ such machines for passenger and air mail services. In the comparatively rare event of one engine failing, the aircraft can remain in flight with the others. Machines can take off and fly in fog, and, in certain circumstances, also land in fog. Navigation in bad weather by means of instruments carried on the aircraft, and by control exercised from the ground, has now been brought to such a fine art that the percentage of regularity is very high and is still improving. There appears to remain only one problem outstanding in regard to navigation, *i.e.* that of landing in dense fog, but such landings are now made and the technique is being further developed. For flying in fog a system of wireless control was evolved so that aircraft flying in one direction were separated by a safe distance from those going in the opposite direction. Risk of collision was further reduced when flying at night or in fog by allotting different altitudes for aircraft flying in opposite directions, and the pilots were in constant telephonic communication with the ground stations which controlled their movements and they received instructions and warnings as they proceeded.

The record of the United States air lines—Pan-American Airways and extensions—in regard to safety was good. In 1935 the passenger mileage was 360,569,431 and 23 persons (passengers, pilots or crew) lost their lives. During the same period the British air lines operated by United Kingdom companies at home and abroad, including all Imperial Airways Empire routes, recorded a passenger mileage of 42,360,000 but 18 persons were killed. The explanation for this difference lies probably in the fact that the conditions for flying in the U.S.A. are, on the whole, better than those prevailing on the Empire air routes; the country is safer and the weather more favourable, though there are regions of difficult and mountainous and desert country and bad weather is frequently encountered. Night flying was regular all over America and the ground organization was developed particularly for that purpose. As the result of considerable aid from the state in the form of subsidies and mail contracts, it was possible to build up a remarkable system which probably had no equal elsewhere, but, as already remarked, the conditions, geographical and otherwise, were most favourable to progress. Wireless communication played an

* Air Ministry Report, "Investigation of Accidents to Civil Aircraft."

important part in navigation as it did on all properly organized air routes. Pilots communicated with a ground station at 10 or even 5 minute intervals when flying over bad country or during poor weather conditions. Should a pilot fail to communicate with a ground station every 15 minutes, calls were made to him and if there was no response to those and to further special signals, a search was begun in the area in which the aircraft was judged to be. This was but one of the many precautions taken to ensure safety in the operation of air transport. On the British air routes the same method of communication was employed. The government authorities provided a meteorological service throughout and before the departure of an air liner the chief pilot or captain was informed of the weather conditions along the route, and during the flight he was advised by wireless of any changes which were taking place ahead. He maintained contact by wireless telegraphy and telephony with the officers at the various airports, and the latter were thus kept informed of the progress of the aircraft. Captains of air liners were also able to communicate with each other during flight. The government also administered an aerodrome control system, which was in force on all air routes. Aircraft had to obtain permission before taking off or landing, and when flying on a regular route had to keep to the right hand and fly at different altitudes. The control officer of an airport informed all pilots as to the position and altitude of other aircraft on the route before they departed and while they were in flight. Elaborate precautions were taken to ensure that all aircraft operating on the regular services were maintained in perfect flying condition. The ground organization provided for rigid inspection at set intervals and the British Air Ministry required a daily report to be made on the condition of all air liners used on the routes of Imperial Airways. The reports included particulars of the day's journey and of any repairs or adjustments which had been made. No aircraft was permitted to leave an airport until a licensed inspector had satisfied himself that the machine was in perfect condition, and periodical overhauls were obligatory.

The principal air transport companies operating in Europe in 1937 with extensions abroad were: Air France, with headquarters in Paris; Deutsch Lufthansa A.G. (D.L.H.) in Berlin; Koninklijke Luchtvaart Mij (K.L.M.) at The Hague; Soc. Anon. Belge d'Exploitation de la Nav. Aérienne (Sabena) in Brussels; Swiss Air Traffic Co., Ltd. (Swissair) in Zürich, and the "Ala Littoria," S.A. (A.L.S.A.) in Rome. All these companies were state owned except the last and operated between London and the Continent in addition to their regular services in Europe. A glance at the map of the European air routes and extensions will convey most vividly the progress which was made in spite of somewhat unfavourable circumstances. Cities such as Paris, Berlin Brussels, Amsterdam, Vienna and Copenhagen had air lines radiating in all directions and Central Europe in particular presented a network of air communications, though the scope and efficiency of the system was unequal to that of the United States of America.

In 1939, the projected transatlantic services were the most important of future undertakings; certainly the problem of flying over the Atlantic regularly was one which had been in mind ever since the airship and the aeroplane were invented, and it was the most romantic of all air adventures. The history of transatlantic flight has already been recorded, and a reference has been made to the regular service inaugurated by the "Graf Zeppelin"

and continued by the ill-fated airship, "Hindenburg" (*see* Plate XXIX). The problem of the Atlantic, particularly the northern crossing, was not only one of great distance, but also of uncertain and often very difficult weather conditions; in fact it was the latter which probably constituted the most serious difficulty. Three routes were suggested: (1) North of Scotland–Faroe Islands–Iceland–Greenland–Canada–NewYork; (2) Ireland–Newfoundland–New York; and (3) England–Lisbon–Azores–Bermuda–New York. The second and third routes were those most likely to be adopted. From Ireland to New York *via* Newfoundland is a distance of about 3,000 miles, of which the greater part is open ocean; the weather conditions over this route, especially during winter, are notoriously bad, and gales accompanied by snow squalls are fairly frequent during that season. There is, in addition, an area over which fog often prevails. Obviously, navigation on such a route must depend on frequent and accurate weather reports covering the whole distance. It was then generally accepted that aeroplanes operating over the route must be flying boats capable of landing on, and riding out, a rough sea should necessity arise. They would have to be heavily loaded with fuel for a non-stop flight of such magnitude, and the loading would naturally reduce the amount of useful load in the form of passengers or mails which could be carried. Refuelling stations in the form of "Seadromes" or other floating structures in the Atlantic were suggested, but the proposals did not then pass beyond the theoretical stage. It appeared that the problem actually centred round the possibility of developing a flying boat of sufficient size to enable a useful margin of fuel to be carried in addition to the pre-determined useful load, upon the transport of which the service was to be based. Such a margin of fuel would have enabled the aircraft to make a detour, if necessary, to avoid the more violent storm centres and, if practicable, would thus have provided an additional factor of safety.

The route from England *via* Lisbon, Azores and Bermuda to New York (or merely by the Azores and Bermuda) though longer, being nearly 4,000 miles, had the advantage of better weather in addition to the possibility of at least two stops *en route*. Cost of operation would, however, have been greater and it was proposed to organize a service on this route in conjunction with the United States of America so that the resources of both countries could be most profitably employed.

Reference has been made here to the special conditions under which a transatlantic air service had to be operated because they influenced development in this country. In connexion with the Empire Air Transport Scheme an order was placed by Imperial Airways, Ltd., in 1935 for twenty-eight new flying boats and twelve landplanes. The former, which were designed and constructed by Short Brothers, Ltd., had a total weight loaded of 40,500 lb., including a crew of five and a "pay-load" of about 3 tons in the standard model. Four Bristol "Pegasus" engines developing a total of about 3,000 h.p. were fitted and the maximum speed was about 200 miles an hour (*see* Plate XXXI). The design provided for two decks within the hull, the upper being occupied by the captain and crew, and the lower devoted to passenger saloons. Much attention was paid to comfort and the aircraft were also designed with a view to meeting the difficult conditions on the Empire routes. Some of these flying boats were employed experimentally on the projected transatlantic services prior to the Second World War and special equipment for long-range

work was undertaken. In addition to this development, two types of aircraft were evolved specially with a view to meeting the conditions of transatlantic operation and they constituted a new and at that time interesting experiment.

The Short-Mayo so-called " composite " aircraft was based on the principle of a large flying boat ascending with a smaller long-range, heavily-loaded seaplane mounted on its upper structure. The latter was fitted with four Napier " Rapier " engines giving a total of some 1,300 h.p. and the former (the lower component) was provided with four Bristol " Pegasus X " engines developing about 3,250 h.p. The purpose of the large flying boat was to assist the smaller aircraft—which was designed for the ocean transport of mails—into the air, and it was hoped that it would be possible by this method to carry much larger loads on the Atlantic route and at higher speeds—but with the expenditure of less power—than would be possible by employing the ordinary method of ascending unaided from the surface of land or sea. As soon as the required operating altitude had been reached the aircraft separated and the flying boat returned to its port. The Short-Mayo composite aircraft represented the highest development of the method of the assisted take-off, but it is unlikely that such a method will be the ultimate solution of the problem in view of more recent advances in the design of power units. Other experiments were undertaken by the German company Lufthansa with flying boats fitted with Diesel engines using a new form of non-inflammable fuel. The advantages of such a power unit were that the weight of fuel carried was slightly less and the risk of fire resulting from a bad landing or other cause was much reduced.

Time saved in any transatlantic air service must be the vital consideration since it is the *raison d'être* for such a service, which must necessarily compete to some extent with cheaper and admittedly safer surface communication. For this reason it does not seem at all probable that transport by airship will provide a solution of the problem, because that form of aircraft is essentially slower. The airship is quite as much if not more subject to adverse weather conditions than the aeroplane, and though she may normally be able to carry a greater load more economically, a part of this margin is necessarily devoted to fuel in avoiding storm centres and bad weather by which she is, owing to her bulk and characteristics, much affected. The evidence of airship operation between Europe and America prior to 1939 showed that avoidance of storm areas, involving deviation from route was an essential part of the safe navigation of lighter-than-air aircraft, and the skill which was then shown called for much praise. It is, however, apparent that a greater speed than the airship can provide is desirable for transatlantic traffic and it is very unlikely that such craft will at any time supersede the aeroplane in air transport; if further developed, their function will be complementary rather than competitive, with perhaps in addition a special and limited scope determined by factors which it is impossible to discuss here.

The crossing of the Pacific by air was regularly undertaken prior to 1939 by the United States service from San Francisco to Hawaii (2,400 miles) and the Philippine Islands (8,200 miles). Large four-engined flying boats of the " American Clipper " type were employed and passengers were carried (*see* Plate XXX). The route passed the Islands of Wake and Guam in the Pacific and an extension from Manila to Hong Kong—already linked with Singapore—was added so that, when transatlantic services were in operation,

it would be possible to travel right round the world on established air routes. In this connexion mention should be made of the Soviet Government's early conception of direct air routes passing over the Arctic Ocean and Soviet Arctic, viz. Moscow to San Francisco, London to Tokyo and Shanghai to New York. Such routes would, of course, actually be the shortest, but many difficulties are involved. The air communications of the world must be based on the ideal of high speed compatible with safety and reliability; the question of comfort in travel is also an important factor where passengers are concerned. Speed should not be increased at the sacrifice of other qualities, and advance in that direction must be gradual.

Considerable advances were made in transatlantic air operation—both in the form of regular services and in ferry services—during the period of the Second World War, but the facts could not generally be disclosed for security reasons. The experience will, however, prove to be of great value.

These notes would be incomplete without mention of some of the outstanding flights which paved the way for the development of regular air transport; though the personal motives were various, the underlying object in each case was that of furthering the development of air communication and demonstrating an advance in some aspect of it. One thing in particular stands out as notable, and that is the manner in which women distinguished themselves in this new field of enterprise; it was perhaps a pointer to future achievement. On May 5–24, 1930, Miss Amy Johnson flew alone from England to Australia, a distance of some 10,000 miles, on a " Gipsy Moth " light aeroplane, and on May 21–22, 1932, Miss Amelia Earhart flew, also alone, from New York to Ireland *via* Newfoundland, this being the first solo crossing of the Atlantic by a woman. Miss Earhart also flew the Pacific solo on January 11–12, 1935—the first crossing by a woman. The first solo flight by a woman from Cape Town to England was made by Lady Heath during the period February–May 1928. Lady Bailey flew from London to Cape Town and back solo during 1928–1929, and Miss Amy Johnson made the first solo non-stop flight from England to South-west Africa during November 1932. In October 1936 Miss Jean Batten made the first solo flight from England to New Zealand in 11 days 1 hr. 25 min., a distance of about 14,000 miles; she also broke the solo record for a flight from England to Australia, which she reached in 5 days 21 hr.

It is not possible to record here all the notable flights of the inter-war period, many of which will be historic, but mention should be made of that round the world accomplished by the airmen Wiley Post and Gatty during the period June 23–July 1, 1931, and the first solo flight by Wiley Post during July 15–22, 1933, when the route followed was New York, Berlin, Moscow, Irkutsk, Khabarovska, Fairbanks, New York, and the time taken 7 days 18 hr 49 min. The flight of C. W. A. Scott and T. Campbell Black from England to Australia (Melbourne) in October 1934, on a D.H. " Comet " aircraft, in competition for the MacPherson Robertson Trophy, was undertaken in 2 days 23 hr. at an average speed of 180 m.p.h.; a Douglas air liner carrying a full complement of passengers and mails also covered the course at an average speed of 156 m.p.h. These and many other flights served the purpose of obtaining information and data which furthered, in some way, the scientific development of aircraft or their operation on a commercial basis. The remarkable achievement of flight over Mount Everest, accomplished on the Houston Mount

Everest Flight Expedition in 1933 by a Westland "Wallace" aeroplane, served to emphasize the capabilities of aircraft in survey work. An altitude of some 31,000 ft. was attained with the aid of a Bristol "Pegasus" supercharged engine of 580 h.p., and the pilot and observer were necessarily equipped with apparatus for the supply of oxygen and with electrically heated clothing.

The records for speed, duration and altitude, etc., increased progressively. In 1931 the development of aircraft for high-speed flight reached a climax when the Schneider Trophy was permanently secured for Great Britain by the Supermarine Rolls-Royce float seaplane S.6.B, which won the race at an average speed of 340·08 m.p.h. and later established a world speed record of 407·5 m.p.h.* In 1934 the record was increased to 440·67 m.p.h. by an Italian Macchi-Castoldi racing seaplane fitted with two Fiat engines developing about 3,000 h.p. It is unlikely that this speed will be very much increased—except in the case of military aircraft—because as the speed of a body approaches the speed of sound in air the effect of compressibility causes a rapid rise in drag, and the problem of cooling becomes acute due to the rise in temperature resulting from such rapid motion. Moreover, aircraft capable of such speed—in this case three-fifths of the speed of sound—have limited practical applications and are of a very costly nature. The duration record in 1935 for aircraft without refuelling was 3½ days and with refuelling 23 days, both held by the U.S.A. Altitude records were frequently being made and broken. In 1937, the world record was 49,967 ft. (15,230 metres), achieved by Squadron Leader F. R. D. Swain on September 28, 1936, with a Bristol low-wing monoplane fitted with a "Pegasus" P.E. VI S. specially supercharged engine developing a normal 400 h.p. An interesting feature of this achievement was the use by the pilot of a special high-altitude pressure suit to increase the pressure in the lungs, as the method of supplying pure oxygen alone through a face mask was found to be inadequate at heights exceeding 43,000 ft. The experience gained is valuable as an approach to the problem of flight in the region known as the stratosphere.

Civil heavier-than-air aircraft were classified generally under the headings of "Light," "Medium" and "Heavy Transport" types, with the addition of racing types produced specially for that purpose, and ultra-light aircraft. Light and medium aircraft had seating for not more than five persons, including the crew, and heavy transport aircraft seated more than five persons. Fairly typical examples of British light and medium aircraft were the Percival "Gull Six" and the de Havilland "Dragonfly" (D.H.90); the former was a three-seater, low-wing, cabin monoplane, with a single engine of 200 h.p. and a cruising speed of 158 m.p.h.; and the latter was a five-seater cabin biplane, with two engines of 130 h.p. each and a cruising speed of 125 m.p.h. The de Havilland "Express Air Liner" (D.H.86A) was fairly typical of a heavy transport biplane; it is a sixteen-seater (including a crew of two) cabin machine with four engines, giving a total of 800 h.p. and a cruising speed of 145 to 160 m.p.h. There was a marked tendency in most countries towards monoplane construction for most civil types and the old acute controversy of monoplane versus biplane appeared no longer to exist (*see* Plates XXVII and XXVIII). The large transport types, including those of Imperial Airways, were thick-wing monoplanes with four engines mounted in the wings, and the practice of fitting retractable undercarriages on landplanes and variable pitch airscrews

* The machine is preserved in the Science Museum.

was beginning to be regarded as essential to the operation of fast services (*see* Plates XXX and XXXI).

In contrast to the large air liners of the period 1937–1939 the ultra-light aeroplane was a minute vehicle. Of these, the machine known as the *Pou du Ciel*, originally developed in France, and the B.A.C. " Super Drone " are perhaps of most interest. The former represented an attempt to construct a really cheap aeroplane which could be assembled, if not entirely built by the owner himself. The design was much simplified to reduce the cost, and, possibly as a result of that simplification it was found dangerous to fly. Modifications improved it, but it is doubtful whether reduction in cost below a certain limit can ever be justified in the construction of aircraft, however desirable a very cheap machine may be.

The " Super Drone " was a more conventional aeroplane; it was a single-seater high-wing monoplane fitted with a Douglas two-cylinder engine of the motor-cycle type developing about 17 h.p., and it had a cruising speed of 60 m.p.h. and a landing speed of 22 m.p.h., with a normal range of about 300 miles. The machine had a landing or take-off run of 45 yds. and the fuel consumption was stated to be 1·25 gallons per hour. A flight by Lord Sempill in one of these machines was significant because it demonstrated what might be accomplished with the ultra-light aeroplane—though, admittedly, by a pilot of great experience—and it brought it into the field of practical aviation. On April 2, 1936, he flew on a " Super Drone " fitted with a special 16-gallon fuel tank, from Croydon to Berlin without a stop, covering the distance of about 600 miles in 11 hours on just under 14 gallons of petrol at a cost of about 15*s*. for fuel and oil. A feature of this flight was the extremely bad weather conditions with poor visibility and heavy rain *en route*. The return journey on April 4 was accomplished in only 9 hours with one voluntary stop and at a cost even lower than that of the outward flight, which had constituted a record for non-stop distance in a straight line by a single-seater aircraft weighing less than 440 lb.

There were one or two unconventional forms of aircraft which it was thought might ultimately provide the means for popular flying. They aimed at reducing the amount of skill required in piloting, thus obviating the risk of loss of control in the air and of accident in taking off or landing. Generally speaking they incorporated a high degree of inherent stability and sought at the same time, very low landing speed and thus ability to operate anywhere. Notable among these was the autogiro, the design of which was approaching finality, and the production of a single-seater model at a popular price was contemplated. It is possible that such a machine, or other form of rotating-wing aircraft, will provide the solution, as it is undeniable that many persons are dissuaded from flying on account of the skill required to pilot the conventional type of aeroplane and the dependance on accurate judgment. The need for a " fool-proof " flying machine is apparent and the autogiro, and more recently the helicopter, approach that ideal. It has been seen that the aeroplane with a high degree of inherent stability was developed during the first decade of flight by J. W. Dunne and others; later the tailless form was improved by Professor G. T. R. Hill with the object of eliminating the danger of " stalling " and retaining the quality of high controllability, and considerable success was attained with the " Pterodactyl " monoplanes. A form of paddle-wheel

aircraft, known as the " Cyclogiro," was experimented with in the U.S.A., and it was said to indicate remarkable possibilities. Experiments with helicopters continued and the Breguet " gyroplane " showed ability to hover and fly horizontally. In the field of engine development the compression-ignition or Diesel engine was slowly coming into its own. The reduction of risk from fire and the possible economy resulting from the use of heavy fuel are important —particularly the former, which alone should justify development—and it is probable that considerable advances will yet be made.

When concluding these notes it is permissible to say something about future progress, though the remarks can only be in the nature of generalizations. The scientific development of the aeroplane appears to fall into definite phases. In its initial stage it had to wait many years for the coming of the internal combustion engine, and during the years which immediately followed it outstripped the engine. From 1914 until about 1930 the aero-engine made more pronounced progress, but since that time advance in the aerodynamic efficiency of aircraft seems to have been the outstanding achievement; the improvement was due to a number of modifications which have all contributed to the general result. Wing and body shapes are better and the surfaces are smoother; discontinuities in those surfaces have been eliminated by covering over openings such as cockpits, and making undercarriages retractable; methods of engine cooling have also been improved by reducing the drag effect of cooling surfaces. The shapes in aircraft have been made to correspond more closely with those in nature and the result is a more efficient flying machine. The use of the compressed-air tunnel has enabled aerodynamic effects to be studied more accurately and the problem of " interference "—the result of the combination of effects—to be explored and faults of divergent air flow remedied. The speed range of aircraft has progressively increased so that there is now a very marked difference between the minimum speed for " taking off " and that for normal cruising; as a result the variable-pitch airscrew has been found necessary to give maximum efficiency under all conditions. By its use less power is required for the take-off, and its influence on the range and pay load of aircraft is considerable. In the future there will still be three main lines of progress which apply to all aircraft, viz. further reduction in wasteful resistance to forward motion, further reduction in the weight of structure, and further improvement in the performances of aero-engines. In regard to the first it appears that we are nearing the limit, for the problem is now largely one of skin friction and no means of eliminating it is yet established. Considerable reduction in the weight of structure seems improbable unless synthetic materials can be produced with much superior properties to those now in use. Improvement in engine performance—of the conventional type—will not be great unless some revolutionary discovery in the conversion of the latent energy of fuel into power is made, though marked increase in power output has been obtained by the use of special fuels of high " octane " number. The recent development of the gas turbine in this country would seem, however, to offer remarkable possibilities in aircraft propulsion. This and the development of jet propulsion will be referred to in the following chapter. It would appear that we are approaching finality in regard to flight in the lower atmosphere, but there remains the problem of flight in regions beyond it (a problem which has already been explored) where the conditions are so different that it is impossible yet to foresee what may be achieved.

The tendency of the future, as of to-day, will probably be towards an " all-wing aeroplane "—a machine in which the fuselage of the conventional type has disappeared and all components which do not contribute to useful lift have been suppressed and all engines, load, etc., are contained *inside* the wing or body. This is an ideal constantly before us.

XIV. AIRCRAFT IN THE SECOND WORLD WAR

WHEN THE DUE PROPORTIONS HAVE been established, it may be found that the period of the Second World War is comparable to that very remote epoch in which Nature, having herself solved the problem of flight, developed the faculty in accord with the dictates of an immutable law. Man achieved flight late in his history, but Nature, also, realized locomotion in the air only in a second stage of the evolution of living forms, the development of wings being the effect of successive adaptation. In Nature the ratio of flying to non-flying species—excluding water creatures—is about three to one, and from this fact we can deduce that the unconstrained motion of flight offered, generally, very favourable conditions for survival. Any appreciation of the animal and vegetable economy of this planet will show how profoundly the conditions must have changed when flight developed, for the flying creatures were able to alight on the islands arising from the sea and the valleys forming on glaciers—pollination and the spreading of life was thereby assisted. The fliers were the pioneers of life and the conservers of the vegetal kingdom. The faculty of flight, which had been acquired in the process of natural selection, was used to escape from preying animals and to reach and collect food more easily ; it was an outcome of the fundamental struggle for existence.

Though it may be a biological truth that, had the organism which ultimately became man acquired the faculty of flight in the process of its evolution it would not have become man, it is nevertheless apparent that the extreme mobility afforded by free motion in the air is a physical accomplishment of a high order. Man, having achieved flight by his technical skill, immediately applied the art (as he applied many arts) in his own struggle for existence. To him, flight was activity wholly in a new element and therefore revolutionary by implication as well as by direct effect; it made possible, among other things the practice of total war; its inception marked the beginning of a new era in the history of the world. The outcome is therefore understandable: viz. that in the urge to dominate, or to resist domination, man should have employed the power of flight to the utmost of his capacity without full regard for the changes in human society and world economy which would indirectly be brought about.

The rise of Fascist Italy and of Nazi Germany was accompanied by an intensive development in military aeronautics in both countries. Air power was identified with the achievement of political power on a world-wide basis and it was largely the growth of air forces which produced the conditions favourable to conflict on the scale of the Second World War. Above all, air power made possible the conception and practice of total war; it facilitated the policy of aggression by contributing to the already unsettled state of Europe a fear based on the assumption of unrestricted warfare in which men, women and children, combatants and non-combatants alike, would suffer. Aircraft became, in the public mind. associated with fear and terror; air power was recognized as the dominant factor in the military aspect of world order. The strength of the German air force had influenced world affairs, and the European situation in particular, during the summer of 1938. The threat of hostile air

"Spitfire XII" High-performance Fighter, 1943

A fighter type which made history during the Second World War It had a maximum speed of nearly 400 m p h and a range of 300 miles.

PLATE XXXIII

"Flying Fortress" Bomber, 1943

American heavy-bomber type used during the Second World War. The aircraft carried nearly 9 tons of explosive and a crew of 10 to 14 persons.

power undoubtedly contributed to the crisis of Munich, but it remains for future historians to reveal the true significance of the existing preponderance by assessing its effect on the whole situation. It is now known that Germany developed her aviation originally as an adjunct to her army, whereas Britain, on account of her island position, envisaged the use of air power largely as an independent striking force—an extension of the policy formulated in 1918 when the Independent Force of the Royal Air Force was established for continuous bombing behind the enemy lines. The policy of the United States of America appears to have included both these conceptions of the use of air power, for a wider range of military types was produced there. In effect, Germany planned and developed the fighter, the dive bomber ("Stuka"), the medium bomber and the purely transport aeroplane to operate in conjunction with the Wehrmacht, while Britain at first developed the defensive high-performance fighter and the medium and heavy bomber types to the virtual exclusion of the more specialized dive-bomber. The intensive development of military aircraft in the belligerent countries proceeded in accordance with the particular strategies favoured, and the general pattern of the air warfare was thus determined. Modifications in strategy influenced, in due course, the design of the aircraft.

It is not the purpose of these notes to discuss the ethics of air warfare, but merely the evolution of aeronautics with reference to the contemporary influences and the technical developments which resulted. It cannot, however, be fruitful to consider these developments without some regard for the motives which inspired them and the changes, social and economic, which they brought about. Thus, and thus only, can a historical review serve a really useful purpose. The interpretation of history is essentially the linking up of motive, action and effect; we cannot escape the fact that most of man's history is but a reflection of his behaviour.

In the earliest stages of the aggression in Poland, the bomber was closely allied to the German military forces in that it was used as powerful mobile artillery in a war of rapid movement. This was its proper function in the campaign—a function more vital to success than the deliberate and ruthless bombing of Polish cities which followed. Initially, both in Poland and on the Western Front, air forces were employed in close co-operation with the armies. The departure from this strategy—as exemplified in particular by the bombing of Rotterdam, where the casualties amounted to some 30,000 dead and 20,000 wounded—no doubt served to hasten the conclusion of hostilities in Holland in favour of the aggressor, but the cumulative effect was to stiffen the spirit of the Dutch people by kindling a deep and abiding anger with the resolve to continue resistance by all possible means. The same reaction of stiffening resistance was observed to follow the bombing of London in 1940, and it is apparent that a strategy which is based on the terrorization of civil populations is unlikely to be decisive unless accompanied by a planned destruction of the means of waging war. It does, however, engender hate, and is likely to produce undesirable social consequences, the nature and extent of which cannot yet be fully determined. We have here a dire example of motive, action and effect which accords with Sir George Cayley's prediction of 1809 that, with the realization of flight, "a new era in society will commence"; and also that of the anonymous writer in "The Times" of 1843 who maintained that it was high time (even then) to consider, in a spirit of careful enquiry, "the social and

political changes which the possession of the new-borne power would necessarily bring about."

The outstanding change brought about by the use, or rather misuse, of mechanical flight was of course the transition of warfare from its traditional form of a conflict mainly between professionals to a conflict of whole peoples involved in ever increasing physical degree—the form of conflict now known as "total war." This practice, which is made possible by the applications of science generally, but in particular by the use of aircraft and long range self-propelled missiles, achieved unexampled proportions during the Second World War. It was accepted apparently by all belligerents as the inevitable concomitant of man's increased knowledge and exploitation of his physical environment. Moreover it was, in a few cases, defended in principle on the assumption that the method was that most likely to create a majority in world opinion antagonistic to war. This is a matter beyond the present scope, but it should be observed that the practice of total war strikes deeply at the structure of society by the lack of discrimination between men, women and children which it involves. How profound and far-reaching the effects, physical and psychological, will be, it is not possible to say as no parallel exists in modern history. The threat which the development of long-range, self-propelled projectiles—notably those travelling in the stratosphere and at supersonic speeds—must constitute to the maintenance of an ordered society should be seriously considered. The employment of such weapons of extreme range, launched direct from their undergound factories, would introduce political and social problems far more difficult of solution than any hitherto faced.

The very diversity of uses to which the power of flight was put during the Second World War is evidence of its dominating and decisive character. For example, it was found at an early stage that armies could not effectively operate in the face of air power—save in exceptional cases—without cover and support from the air. It was revealed that neglect of this principle generally resulted in the defeat of the forces lacking air support or possessing it in an inferior degree. An increased development of specialized types, and the modification of others for close co-operation with ground forces, therefore took place. It was further revealed that sea power could not operate effectively in the face of opposing air-power without the protection of air cover, and this fact, somewhat tardily recognized, resulted in more production of aircraft modified or specially designed for use in ships—aircraft carriers—as a bare necessity where land-based fighter cover could not be provided. In short, the outstanding lesson learnt during the War was the fundamental importance of air superiority in military and naval operations. It is understandable, therefore, that the development in military aircraft which took place during the years 1939-1945 even exceeded in intensity that of the historic period 1914-1918 when the aeroplane grew from a tentative and generally untried instrument into a specialized weapon. The advances were mainly on the lines of the earlier war and inter-war periods, viz. speed, rate of climb, manœuvrability, endurance, armament (fire-power) and load-carrying capacity, in accordance with the requirements of the different types. Many refinements were, however, introduced and the whole tendency was towards increased complication.

Though the vital rôle played by aircraft in the preparation for military operations by attack on war production, lines of communication etc., and in subsequent close support of those operations were fully realized, there was

throughout a tendency to divert air power from what might have been regarded as its orthodox military use to other uses determined by considerations of a more political character. The effect of this, the most pronounced single tendency of the Second World War, was to transfer much of the burden of conflict from the armed forces to the civil populations in general accord with the fundamental strategy for air warfare enunciated so prophetically by Giulio Douhet.* The outstanding example of this tendency was the diversion, in 1944 and 1945, of aircraft manufacture from the Luftwaffe to the production of pilotless bombers or "flying-bombs" and to rocket projectiles intended to destroy London. Had the remarkable ingenuity and considerable resources devoted to these devices been employed by the enemy in the development and construction of improved types of service aircraft, his military situation might not have deteriorated so rapidly. But obsession with efficacy of "secret weapons" generally and delays in development and production, involving somewhat premature use, tended to mitigate against the effectiveness of these weapons though not to impair the technical brilliance of their conception or their significance as pointers to future methods of warfare.

The chief characteristic of the German flying-bomb was the application to flight and use for the first time on a production basis of the method of jet propulsion, which constituted the outstanding aeronautical advance of the Second World War and so deserves special emphasis here. It will be appreciated that the idea of jet propulsion is ancient and dates, at least, from the project of Hero of Alexandria in A.D.50. Furthermore, the research undertaken prior to and during the war in the development of gas turbines—culminating in this country in the very successful propulsion unit evolved by Air Commodore Frank Whittle and others—served to advance the theory and practice to a stage where its application to aircraft could be seriously entertained. The several advantages and therefore the significance of this method—particularly for military purposes where speed is of more consequence than thermal efficiency—was apparent to aircraft designers in most countries, but the credit for having first demonstrated its qualities in a simple and effective manner—viz. in the V.1 flying-bomb—must be accorded to German engineers. Moreover, the employment of jet propulsion in conjunction with automatic piloting and navigating devices—as in the case of the flying-bomb and the V.2 rocket bomb—may prove ultimately to be of value in high-speed communications. As an alternative to the conventional type of aero engine, the jet-propulsion system will also present considerable possibilities in civil air transport.

The principle underlying the several variants of jet propulsion (excluding that of the rocket bomb) is, broadly, that air is drawn into the leading part of the propulsion unit—e.g. through the leading edges or nose of the aircraft—compressed to a very high degree, mixed with liquid fuel, and then fired in a combustion chamber. The gases, expanded by the heat thus generated, are finally expelled at great speed through jets or nozzles in the rear of the aircraft and this discharge may be a continuous process. The purpose of a gas turbine in this system, if such a device is employed, is to provide the power necessary for driving the air compressor and thus very much increasing the overall efficiency of the power unit. It should be understood that propulsion is effected solely by the reaction pressure against the aircraft itself—analogous to the recoil of a gun on firing—and not by any force that is exerted on, or pushes

* Douhet, G. "The Command of the Air," 1921

against, the atmosphere behind the aircraft. As jet propulsion does not employ its energy directly on the atmosphere, as in the case of the air propeller, i should make possible much more efficient operation in the rarefied air of the stratosphere than can be obtained by the conventional method of propulsion. This will probably be its principal advantage, for by opening up the sub-stratosphere and stratosphere regions where meteorological conditions ar more constant and speeds far in excess of those feasible at lower altitudes ma be obtained, we approach more nearly to the ideal of perfect unrestricte motion. Communications within the orbit of this planet may thus be s improved as to bring about profound changes in the course of human histor

The choice of a variety of possible fuels, and also a considerable simpli cation of aircraft design, are further advantages of the jet propulsion syste. We cannot fail to reflect that its perfection for aircraft will have far-reachir consequences; and also that its initial development and first practical applica tion was due to the stimulus of preparation for, and conduct of war.

Another outstanding development during the Second World War was the advancement of the helicopter to a stage never previously attained. As in the case of jet propulsion, the idea—that of achieving controlled ascent sustension and descent solely by means of air propellers—is of very early dat the original proposal being attributed to Leonardo da Vinci, c.1500. But tl inadequacy of power-units generally, and other factors connected with th design of rotating-wing types, prevented any considerable success being achieved—particularly with regard to the combination of vertical ascent an descent with the ability to hover and to accomplish horizontal flight. Tl advances in aero engine design and in that lifting of airscrews, and in the arrangement, culminated however in the production of helicopters capab of all these manœuvres. Notable among such machines was the Vought-Sikorsky helicopter, VS-300, which was experimentally developed by Mr. Igor Sikorsky in the U.S.A. and flown by him in 1941 for over an hour and a half—an improvement on the previous record held by Germany since 1937. Development and modification of this particular machine, and its adoption by the U.S Army Air Forces in 1942, have resulted in the helicopter type becomir established as a practical form of aircraft. Its use in war will probably b confined to reconnaissance duties—for which, especially as a ship-borr aircraft, it is admirably suited—but a wider application in the realm of civi aviation may be anticipated. Ability to rise and descend vertically while under full control; to be capable of remaining stationary or almost stationary in the air; and to have a wide range of horizontal speed—e.g. from zero to 100 m.p.h.—these are qualities which should be invaluable in the air transport of the future as a means of leaving and approaching closely built-up areas and thus providing the essential feeder services. The potentialities of the helicopter as a vehicle for private use in conditions unsuitable to the conventional aeroplane and, generally, as an aircraft independant of large landing grounds should be great. It is worth noting that this invention—the practical development of which was so long delayed—was also brought to fruition during a period of less stringent economy in research when normal commercial standards no longer applied.

It is also worth reflection that the method of flight by means of rotating planes (rotors) arranged to produce lift *directly*—to which group the helicopter belongs—approaches more nearly to the general method of nature than that

of the aeroplane where the lift is obtained by planes stationary in relation to the machine. In the latter case, support is derived from the *continuous* propulsion of the fixed planes through the air—a system which does not appear to have an exact counterpart in natural phenomena. The helicopter, on the other hand, deriving its support from the reaction of the air on one or more power-driven rotors, has an anology in nature as exemplified by the continuous operation of the wings of the majority of insects and of many birds when in flight. Undue significance should not be attached to this resemblance, but it does emphasize that the methods evolved in nature always deserve the closest investigation.

* * *

It will not be possible to assess the exact value of the contribution which air power made to the success of the United Nations in the Second World War until some time after the event. There can be no doubt that many of the technical advances achieved will be of use in the future development of civil air transport, though from the standpoint of commercial efficiency, experience has shown that the forcing house of war is not wholly beneficial. Immediate benefit is most likely to accrue from the organization, constructional work and operational experience which was one result of those years of conflict. A great network of airfields, flying-boat bases and repair depots were established, and in the aggregate there was more purely transport aviation than at any time prior to 1939, due to the operations of the R.A.F. Transport Command and the U.S. Army Transport Command. The centenary of transatlantic steam navigation in 1938 marked an epoch in that the steam ferry was being supplemented by an air ferry and one great social consequence of flight was becoming apparent. By the middle of August 1944, the Atlantic had been flown on no less than 20,000 occasions and the time occupied in the journey from shore to shore had been almost halved.

The extent to which the construction and development of aircraft increased during the Second World War is shown by the fact that in 1944 the aircraft industry was the largest single industry in Britain, employing some [illegible],000,000 operatives. But it must be borne in mind that there is hardly a major industry, or indeed branch of science, upon which the practice of flight does not now make a call; nor even a profession which is not in some way affected by its special requirements. The physicist, the civil engineer, the electrical engineer, as well as the mechanical engineer, are all involved. Medical science and chemistry have had to make their contributions, and the vital need for improved communications has resulted in the development and perfection of Radar. This invention is undoubtedly most valuable in its application to aeronautics. For many years a radio-pulse technique had been in use to determine the height and nature of the ionosphere, and its adaptation for the location of aircraft followed. A radio wave sent out from a transmitter was found to set in oscillation all metal structures in its path, and in spite of any attempt at screening, the oscillations could be detected on re-radiation and measured by sensitive radio direction-finding apparatus. The energy available for detection was very small, and the success of the method was due to the very great amplification factor introduced in radio, without distortion, which enabled information concerning the approach of aircraft to be received at a speed approximating to that of light. It is obvious that the importance of this

invention to aviation, both in war and peace, is immense, and its use for navigation under "blind" conditions opens the way to much increased safety in flight.

Another development of the war-period—briefly mentioned at the beginning of this chapter—must not escape consideration because of its terrible implications, but should rather provoke discussion on that account. For the German V.2 jet-propelled missile, or rocket bomb—which on account of its technical features may be classified as an aircraft—opens up such possibilities in any future warfare as to form an even graver threat to civilization than that which the conventional bomber aircraft may have constituted. The principal characteristic of the V.2 missile is that (up to the time of writing) it cannot be intercepted in flight and that its speed is such that it is not practicable to give warning of its approach. The device being still in an experimental stage, it is not feasible to estimate what the ultimate limitations may be in respect to speed, range and accuracy of aim, but sufficient information is available to indicate that its scope of operation may be increased considerably beyond the nominal 200 miles achieved at the outset. Moreover, the supersonic speeds attained and the methods of controlling the missile render it improbable that an adequate system of interception or of warning can be easily, if at all, devised. This very ingenious and complicated machine appears to have been the outcome of some 20 years of *ad hoc* research in Germany and elsewhere on the subject of direct reaction-propulsion by means of liquid and other fuels, with the ultimate object of achieving so-called "stratosphere flight." Rocket propulsion had, moreover, an obvious application in the development of a self-propelling shell or explosive missile of considerable range in so far as it was the only known method of propulsion which derived all its power from the fuel carried and was not dependant on external air for combustion. Accounts of such projects were published from time to time* describing the characteristic of supersonic speed—rendering warning of approach impracticable—obtained by the use of liquid fuels in conjunction with a very high trajectory; so that the introduction of such a weapon during the Second World War could by no means be regarded as unforeseen.

The V.2 rocket bomb in its original form—September 1944—was 46 ft. long and 5½ ft. in diameter. When loaded, it weighed 12 tons, 1 ton of which consisted of explosive. Propulsion was obtained by the burning of alcohol (approx. 7,500 lb.) with liquid oxygen (approx. 11,000 lb.) in a large combustion chamber and venturi into which the mixture was forced through a series of jets by turbine-driven pumps, the latter being actuated by super-heated steam produced by mixing concentrated hydrogen peroxide with calcium permanganate solution. On launching, the mixture was ignited electrically and thereafter continued to burn with great violence, the products of combustion being forced out at great speed through the orifice at the rear end of the venturi. The process was completed within a minute or two by which time the projectile had attained a speed of about 3,000 m.p.h. and entered the stratosphere—viz. reached an altitude of some 60–70 miles. The propulsive thrust was stated to be about 26 tons, and on automatic cutting off of the fuel, the projectile continued on a flight path similar to that which a shell would follow. The initial range was some 200 miles and that distance was covered in about 5 minutes after launching in a nearly vertical plane. Control surfaces in the form of external vanes on the edges of four stabilizing fins, and internal

* Eg. "Whitaker's Almanac" for 1940.

vanes operating in the jet stream, were employed. These were operated by a gyroscope control automatically, causing the projectile to curve from the vertical towards the target; the point at which the fuel was cut off determining the range within certain limits.

The V.2 did not prove, either strategically or tactically, to be an adequate substitute for an orthodox air force; but, as in the case of the flying-bomb, it was employed prematurely as regards scientific development and quantity production—in fact its use was in the nature of an experiment. The purpose of such a weapon in any future war would, it is assumed, be to produce the maximum results in attacks on persons, possessions and morale at a minimum cost to the attacker; so that any further improvement of the device with regard to range and accuracy could not fail to constitute a grave menace to world order.

* * *

In concluding these notes on the development and use of aircraft during the Second World War it is appropriate to revert to the analogy which seems to exist between the function of flight in nature and its function in human affairs. From the limited knowledge available, it is apparent that the changes in the conditions of organic and inorganic life which followed the evolution of flying creatures were profound, and it is evident that, during the period in which man has most vigorously exercised the same faculty, changes of corresponding proportions occurred in his conditions of life. These changes—both physical and psychological—affected approximately half the population of the world and they were brought about solely by the use of the faculty in the military sphere. The changes comprised the spreading of a mental state of anxiety and fear among communities and groups where similar conditions had never previously existed—at least in such an acute form; they comprised the movements of populations (evacuation and dispersal) on a scale never hitherto undertaken; they comprised violent destruction of life and property of a magnitude never before experienced—moreover they were changes not of an ephemeral character, since the repercussions must long outlast the generation which endured the war.

It is not constructive to maintain, or merely to remark, that the changes, undesirable or otherwise, were inevitable. Man would not be man were he not able to control in some degree the course of his destiny. What is necessary is that he should, inspired by the example in nature, appreciate to the full the revolutionary implications of the new faculty and endeavour, by exercise of the highest statesmanship, to regulate the function of flight in order at least to avoid violent and unforeseen reactions. A new conception of transport has already arisen as a result of the war development in aviation. It is global in character ignoring the obstacles placed by nature on surface travel; it is concerned only with the shortest distance between any two places on the face of the earth and it admits of no physical restriction. As the growth of civilization is in reality the facilitation of transit, this development of aviation is likely to bestow on those who operate and control it quite exceptional opportunities for the dissemination of their particular culture. Should a monopoly of air transport be secured by any one nation or group of nations, the power to cut off air communication in any quarter of the globe would be

invested in that unit or group and might constitute a threat to the general standard of civilization. Moreover, a monopoly in the control of civil air transport would establish also a monopoly of air power.

The history of man's use of flight shows that, up to the present, it has proved decisive in the struggle for existence. So many trades and activities can now be included in the term "aeronautics," that the future of large numbers of men and women will be influenced by the progress of air transport hereafter. The requirements of peace are, however, very different to those of war, and it is questionable whether any but a small fraction of the individuals formerly engaged in the production of aircraft will continue to be connected with that industry. It is, however, of great importance that the now established tradition and cadre of flight in this country—as exemplified by all these activities and strengthened by the remarkable achievements of the Second World War—should not be allowed to wane. The design of aircraft and their power plants is still in an early stage and no human mind can yet measure the full possibilities of this new system of world communications.

XV. THE SOCIAL AND ECONOMICAL SIGNIFICANCE OF FLIGHT

ALL WHICH PRECEDES THIS CHAPTER is evidence for certain conclusions; it is idle to consider flight apart from the uses to which it may be put and its potential value.

Many of us are perhaps more concerned to know whether we shall be annihilated by the new instrument than whether it will prove ultimately to be of great benefit to humanity. But that is merely thinking of flight in terms of offensive strength, and it is not the best attitude for an impartial inquiry, however much it may be imposed by conditions during the Second World War. It is becoming increasingly obvious that our knowledge and control of what may be termed the material world—of which the science of mechanical flight is an example—far exceeds that of the mental world, and thus, we may easily be stultified by the power we have acquired. The real significance of a new invention may escape us because our knowledge of ourselves and our individual and social relations is inadequate, and, if so, we shall be unable to use it to the best advantage. Moreover, as in the case of flight, it may become a menace rather than an aid to civilization. It is now widely accepted that the aeroplane and other mechanical devices which travel through the air, when employed for offensive purposes, are such effective weapons that they have practically abolished defensive warfare, and that the only adequate protection against attack from the air is the abolition of war itself. However that may be, it is clear that the question of how to use the power of flight is an international rather than a national one, and that the fate of man and his civilization may still depend upon the answer. The use of aircraft for destructive purposes is but one illustration of the fact that man's scientific knowledge of his material environment has outstripped his knowledge of his own mind and society, and the amelioration of this unstable condition is the outstanding problem of our age.

What, then, is the real significance of flight ? One thing is certain, and that is its dominating influence in human affairs, particularly in war. The experience of the Second World War has shown, beyond any shadow of doubt, that air power is the most decisive factor; similarly, in the normal social and economic life of nations it will be found that the possession of adequate and efficient air transport will be a vital aid to progress. We have seen that the achievement presented very great difficulties to man in his continued efforts to gain control over the natural conditions of his environment, in so far as it involved exploration in a medium previously unexplored, and introduced problems far more abstruse than any of those connected with locomotion on land or on water. This medium—the air—being all-pervading with regard to the earth's surface, unobstructed and free, provides unique facilities for transport; it is, as Cayley remarked, "an uninterrupted navigable ocean, that comes to the threshold of every man's door." Moreover, it has that combination of density and fluidity which makes it the best medium for very rapid motion. Space has ever been regarded as synonymous with freedom, and flight is movement in space unrestricted by natural obstacles: illimitable and thus free. So free, indeed, that speeds which are unknown in other forms of

transport are possible and there is as yet no definite limit to those which may be achieved, except perhaps the physical limitation of man himself to endure them.

The significance of flight depends on the place it occupies in the struggle for existence. History has shown that mobility has played an overriding part in the development of organized political and social groups. Transport—particularly rapid transport—has facilitated the growth of such groups, and it is easy to see that the mobility accorded by the aeroplane far surpasses any hitherto known. It is for this reason that the bearing of flight on the question of world order and progress is profound.

The principal advantages are, of course, speed and the ability to travel anywhere independent of specially prepared routes or charted waters, but not—as yet—entirely independent of weather conditions and of spacious landing grounds. It is unlikely that flying will ever be a cheap method of transport compared with the older methods, on account of the high power required to maintain a machine in the air. But it is by far the most economical way of travelling very quickly and, taking this into consideration, it is in some circumstances the cheapest of all. If speed is of value, then the flying machine will be the best way of securing it. Moreover, the speed is obtained with a minimum of the discomfort inseparable from very rapid transport on land. It is not, of course, necessary to have a very fast aeroplane—which in the present stage of development requires more skill to operate and also more space for taking off and landing; slower machines are available which are correspondingly easier to handle and more economical in use. The practical flying machine of the future may have a considerable range of speed and it may be equally safe and controllable at all speeds. That would make navigation—especially in fog—much easier, and reduce the risk of collision by giving the pilots more time to think and act in an emergency.

The question of safety is paramount if flying is to be established properly as a means of transport. The Wright brothers realized—perhaps better than anyone else—how damaging the idea of great danger would be to the development of flight, and so they never took unnecessary risks because they knew that—apart from the loss of their own lives—in the long run confidence was what really mattered. To-day a high degree of safety has been reached and accidents are due not so much to failure of the machine as to that of the human element and to faulty technique of flying. That is a matter which certainly demands attention; the machine must be developed to eliminate, as far as possible, the risks resulting from human failure, because in the air that failure may have even more disastrous consequence than on land or water. Air transport already compares very favourably in safety with the other methods of travel. The statistics issued—coupled with the fact that the insurance rates for passengers compare well with those for rail and boat transport—show this to be the case.

In addition to its function in transporting passengers, mails and freight over long distances at high speeds the aeroplane has many other uses, and it is necessary to consider some of them if a true idea of the scope and value of aircraft is to be obtained. So much notoriety has been given in the past to flights of a spectacular nature—which were in many cases feats of physical endurance on the part of those concerned rather than evidence of practical utility—that the more profitable employment of aircraft has often been overlooked.

One of the outstanding uses to which the aeroplane has been put is that of aerial survey. There are still many thousands of square miles for which no reliable maps exist, and it is sometimes impossible to effect a survey from the ground—as in the case of the Upper Amazon, where, in 1924–25, a remarkable exploration from the air was undertaken and a distance of some 12,000 miles was flown. It has been stated that survey work which would previously have occupied years can be carried out in a month by this method. The chief cities of the world are now photographed from the air to assist in street planning—a technique which has been developed from the practice of aerial photography during the First World War. Aerial survey has also enabled mineral deposits to be discovered in Canada and elsewhere and new industries have grown up.

In food production and in agriculture the aeroplane has proved invaluable. Crops growing on large areas have been protected from the ravages on insects by "dusting" with special preparations, and poison has been sprayed on tobacco and fruit plantations from low-flying aeroplanes in less time than it could be distributed by other means. Insect pests have also been eradicated by transferring supplies of their natural enemies from one district to another and distributing them. Rice and grass seed have been sown over large spaces by aeroplanes in a few hours—notably in the U.S.S.R.—and the crops protected while under cultivation. The aeroplane has been used to find food by observing shoals of fish and informing fishermen, also for the prevention, by patrol, of illegal fishing. Movements of big game in Africa and of buffalo in Canada are most effectively observed by aeroplane, and the herding of reindeer in Alaska provides a good example of a use whereby, it is said, work which would take six men one week on the ground can be accomplished in two hours by the use of aircraft. Protection of forests in Canada against fire during hot weather was also undertaken by aircraft and it is estimated that a quarter of a billion acres have been patrolled.

The value of the aeroplane for transporting medical supplies, doctors and patients rapidly—particularly in remote parts of the world—is very great, and it is on record that many lives have thus been saved. The British Red Cross Society is among those organizations which employ that method. The evacuation of the whole European population of Kabul during the civil war of 1928–1929 is an early example of the use of aircraft for relief purposes. Whenever speed and direct communication are essential the aeroplane is valuable; in the transport of bullion from one capital to another, or in the transport of animals and perishable goods which suffer less in transit by air—on one occasion some thousands of young swallows, benumbed and exhausted by the early approach of winter, were taken by aeroplane from Vienna to Southern Italy—or in any case where the time saved is a vital factor, the flying machine can be employed with profit. In exploration it has superseded other methods of travel. It made possible, for instance, the expedition led by Commander Byrd to the South Pole in 1929 when some 20,000 square miles of land, hitherto unknown were discovered, and it made feasible the survey of Mount Everest in 1933. Even in archaeology it has found a use—for example, some discoveries of ancient cities and settlements in French Indo-China were the result of observation from the air. In England, control of road traffic by means of the autogiro proved most successful.

These are not all the uses of the aeroplane, but they give some idea of

its potentialities; there are uses for which special development is desirable—development which is likely to be hindered if the design and manufacture of aircraft continues to be determined largely by the particular requirements of the naval and military air forces of the world, and the productive resources are employed mainly for that purpose. In other words, the maximum benefit will not be derived from the power of flight if the offensive and defensive quality of aircraft continues to be emphasized. This misdirection of scientific effort was all the more deplorable because it resulted in the production of a weapon which far surpassed in mobility, and thus in effectiveness, any previously used and it introduced a new method of attack. The history of warfare shows that new weapons and methods of attack have always had a decisive influence until a counter or defence measure has been devised and used effectively against them. The introduction of gunpowder towards the end of the Middle Ages represented such a weapon, but, profound though its influence has been, it cannot be regarded as comparable to the aerial weapon because the latter has the quality of extreme mobility which, used in conjunction with the former, renders defence difficult. No wholly effective counter-measures, except retaliation in kind, can be taken, and mitigation, which in the past has always been possible, is not now assured.

For these reasons the aeroplane as an invention applied for destructive purposes is in an unique position. The internal combustion engine which has made flight and jet propulsion possible is, in that application, a greater menace to civilization to-day than was gunpowder as a propulsive agent in the fourteenth century. It is important to realize that a quite outstanding stage in the progressive application of scientific knowledge for destructive purposes has been reached, and there can be no conflict in reasoned thought as to the desirability of checking the further extension of aerial warfare and repudiating methods which have been described as those of cultivated barbarism. The problem is far greater than that involved in the question of naval and military power for, from a national standpoint, the possession of an excess of air power is not necessarily a protection, since operations depend largely for their success on the factors of mobility and surprise. In addition, unlike other transport machines, the large civil aeroplane is a potential weapon capable of adaptation and use for bomb-carrying; so that organized civil aviation is in itself a reserve of offensive power. The Spanish civil war provided evidence in 1938 that the application of standard passenger-carrying machines for bombing purposes is feasible and effective. Moreover, it is impossible to deprive commercial aircraft of their offensive capabilities without much reducing their practical utility. On the other hand, small aircraft of the interceptor fighter class rely for their offensive power on very high speeds and performances—qualities which are not possessed by civil machines of comparable size—and they function more as defensive than as offensive weapons. The use of such aircraft might well be allocated to police duties, as they constitute a less serious threat to civil peace. It is essential to differentiate broadly between the types of aircraft which may constitute a grave menace to society and those which are not potentially so destructive; many technical considerations must of course be taken into account, but a general differentiation is permissible without going into those details.

It is clear that the invention of the aeroplane and the jet-propelled bomb has altered fundamentally the conditions of warfare. The history of

their application for that purpose, which has been briefly described in this book, shows that it tends to impair freedom of judgment and command of initiative in particular cases where previously those privileges were secure.

Various proposals have been advanced—primarily in the interests of peace—to reduce or remove the threat of aerial warfare. The proposals are concerned more with the mitigation of warfare or its abolition than with the object of securing the greatest benefit to mankind from the use of the new gift of flight. It is assumed that with limitation or total abolition of aerial armaments there will be a corresponding release of effort and resources for constructive purposes. Proposals for the control of air power by abolition, limitation or international control are thus of interest to the engineer and to students of mechanical flight—apart from any political aspect, with which we are not concerned here—and it is desirable to consider them very briefly.

The abolition of offensive aerial power if it is to be effective will, as already remarked, involve the abolition also of all commercial aircraft which are capable of being used for bombing purposes. Clearly such a course is unthinkable, for it would amount to an act of regression and constitute a negation of principles whereby man, by gaining control over the natural conditions of his environment, has reached the position he now occupies. The limitation of offensive air power in the form of national air forces with the potential reserve, which a commercial air fleet constitutes, would depend on international agreement which is difficult to secure; and to be effective the limitation should extend to all potential reserves which, in practice, would tend to impede the growth of civil aviation. The principle of international control of air power in some manner has frequently been advocated. The proposals may take the form of an international air police force, such as that defined and submitted to the International Congress in Defence of Peace held at Brussels in 1934, or they may be conclusions such as those recorded at a Conference in 1932 of the General Disarmament Commission, appointed by the League of Nations, and referring in general terms to the prohibition of air attack on civilian populations. It is generally agreed that progress on these lines has become increasingly difficult and inappropriate to the re-orientation following the Second World War.

It would appear that we must look for some solution other than those which have already been suggested, because they tend to evade the fundamental problem which is, broadly speaking, to unite science with human values. So that what is required is not so much control of the instrument, as man's control of himself by more scientific study of his own mind and society. The internal combustion engine has brought not only the aeroplane and the rocket projectile but also the motor car, and the latter, in application, has caused greater devastation than any other instrument devised by man for his own delectation. The destruction of human life which has resulted from the general use of the motor car all over the world now exceeds the losses which, it is estimated, resulted from the frequent wars during the middle ages of our civilization. It is an example of what may ensue from the imperfect use of an instrument of communication which represents the accumulated scientific knowledge and experience of generations applied for the satisfaction of human desire and to improve the amenities of life. An explanation for this self-destruction may be sought in man's lack of moral self-control, and it is well to recognize this defect since it is at the root of the problem now confronting us. The advance

of scientific knowledge has not been accompanied by a corresponding development in the realms of ethics and more knowledge of the human mind and its behaviour is needed. Man's knowledge—and thus control—of himself is fundamental to the proper use of the aeroplane as it is to the use of the motor car.

It is apparent from the history of aeronautics that the engineers and technicians who actually developed the aeroplane were not concerned with the moral or political results of their work; on the other hand, men such as Cayley appear at least to have realized the social and economic implications. The function of the engineer is to apply the co-ordinated knowledge of the man of science and the accumulated experience of ages to the increase of the amenities of human life. His contact with humanity should thus be closer than that of the research worker in pure science and it is logical that we should look to him for some control of the instruments which he has created. Therein, it is suggested, lies hope for the proper application of scientific inventions—and in particular aircraft—to the enrichment of human life.

It has been seen that, since the invention of the aeroplane, aviation has grown very rapidly; but there was apparently no corresponding advance in friendly intercourse between peoples, or any indication of a beneficial influence in that sense, and relations became more and not less strained due, in part at any rate, to the fear of devastation which air power brought in its train. The world expenditure on offensive and defensive air power probably exceeded five hundred million pounds annually prior to 1939, and the expenditure did not result in any universal feeling of security—rather the reverse, since it made possible the practice of " total " war. During the Second World War, the expenditure in all countries surpassed computation.

It is necessary to consider these facts if one considers flight at all. They concern the man of science, the aircraft engineer and the air pilot—in short all who are occupied in the creation, construction and use of aircraft—as much as the ordinary citizen. No one can wholly escape responsibility, but those who are engaged in the world-wide science and calling of aviation should be in a better position to influence and to exercise that measure of control which is essential if the machine is not ultimately to destroy the mind that made it. Man's reaction to the changes which the advance in exact knowledge and its application have brought about—so aptly described as " the impact of science upon society "—is the basic consideration. A new philosophy is required to meet the changed conditions—in this case the condition resulting from the introduction of new and potent weapons—and it may well find expression in a reconstitution of authority, so that, in the realm of scientific attainment, control of such inventions as may constitute a great threat to society will be vested in some international body.

In the specific case we are now considering—which is such a glaring example of human failure—the principle may prove feasible since there exists an increasing community of spirit among airmen and technicians of all nationalities which may one day exercise a profound influence. A more active co-operation between those learned societies and other organizations, whose declared purpose is to disseminate knowledge and further the cause of flight throughout the world, may also prove beneficial. It is significant that the identity of purpose which in the past has been a characteristic of workers in scientific research is now extending to those who operate the machines, and

in particular to those who fly. The tendency is one which should be carefully fostered because, in the fullness of time, it may render the aeroplane the most effective of all instruments for promoting and maintaining world peace.

The question of the use to which scientific inventions may be put leads, of course, to the root of all human organization; to the fundamental problem which has occupied man from the very beginning—the problem of co-operation or conflict. There is, however, a justification for attempting to isolate one particular branch of technology—that of flight and its concomitants—from other human activities, because this has proved already to have social consequences more far-reaching than those which followed the earlier achievements of science. It would not be necessary to recapitulate these consequences were it not that man, with his innate optimism, tends to be forgetful of evil when the immediate danger is passed.

Total war has been the principal consequence of flight. It is fallacious to assert that the nature and scale of the conflict which we have just experienced can be attributed to any other factor, or that air bombardment is without effect on the minds of those who survive. The undercurrent of anxiety to which whole populations are subject in this form of warfare is not without its danger to the future organization of society; but it may also perhaps have a long-term beneficial result. The anxiety which such experience engenders probably finds a rational outlet as long as the war continues, but afterwards it and the accumulated resentment may become attached to, or be evoked by, situations which do not justify such emotions. The most pronounced effect of total war, as already observed, is the transfer of much of the burden of warfare from the recognized combatants to those hitherto regarded as non-combatant and not subject to military discipline—notably women and children. For example, during the first five and a half years of the Second World War the total number of lives lost in the United Kingdom forces (in all services in all theatres of war) was 216,287, and the total number of civilians recorded as killed by enemy action in this country was 59,793*—somewhat more than one quarter of the military losses. The corresponding figure for the First World War (1914–1918) was in the order of one five-hundredth.

It is probable that in any future conflict the disparity would be even further reduced, so that ultimately there might be little if any difference between the losses sustained by military personnel and by that regarded as non-military. As the former must depend in ever-increasing degree upon the productions of the latter in the factories, it will be seen that distinctions hitherto recognized now tend to become unreal and the full implications of one use of flight are apparent. This revolutionary change in the conditions of warfare demands a re-orientation of society if the future is to be safeguarded. The re-orientation may possibly take the form of a reconstitution of authority in all countries, occurring spontaneously as the result of man's appreciation of the threat which air-power constitutes to his civilization and leading, in due course, to a revolt by all peoples against war.

Meanwhile we cannot do other than revert to the interpretation of the history of human flight—the historic background which may influence to some extent the behaviour of future generations of airmen. We find that the honours are fairly equally divided. In Italy the Renaissance produced the

* The intrinsic damage was provisionally estimated at £1,000,000,000.

reasoned speculations of Leonardo da Vinci and Francesco de Lana; France produced the balloon and the first airship; in England Sir George Cayley defined the aeroplane, and in Germany Otto Lilienthal experimented in the air and the internal combustion engine was born; America produced the Wright brothers and the first successful aeroplane, while from Spain came the invention of the autogiro and from Russia the inspiration of mass air-mindedness.

Is it too much to hope that this world-wide division of responsibility for the development of human flight may lead ultimately to a like sharing of the responsibility for its use?

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